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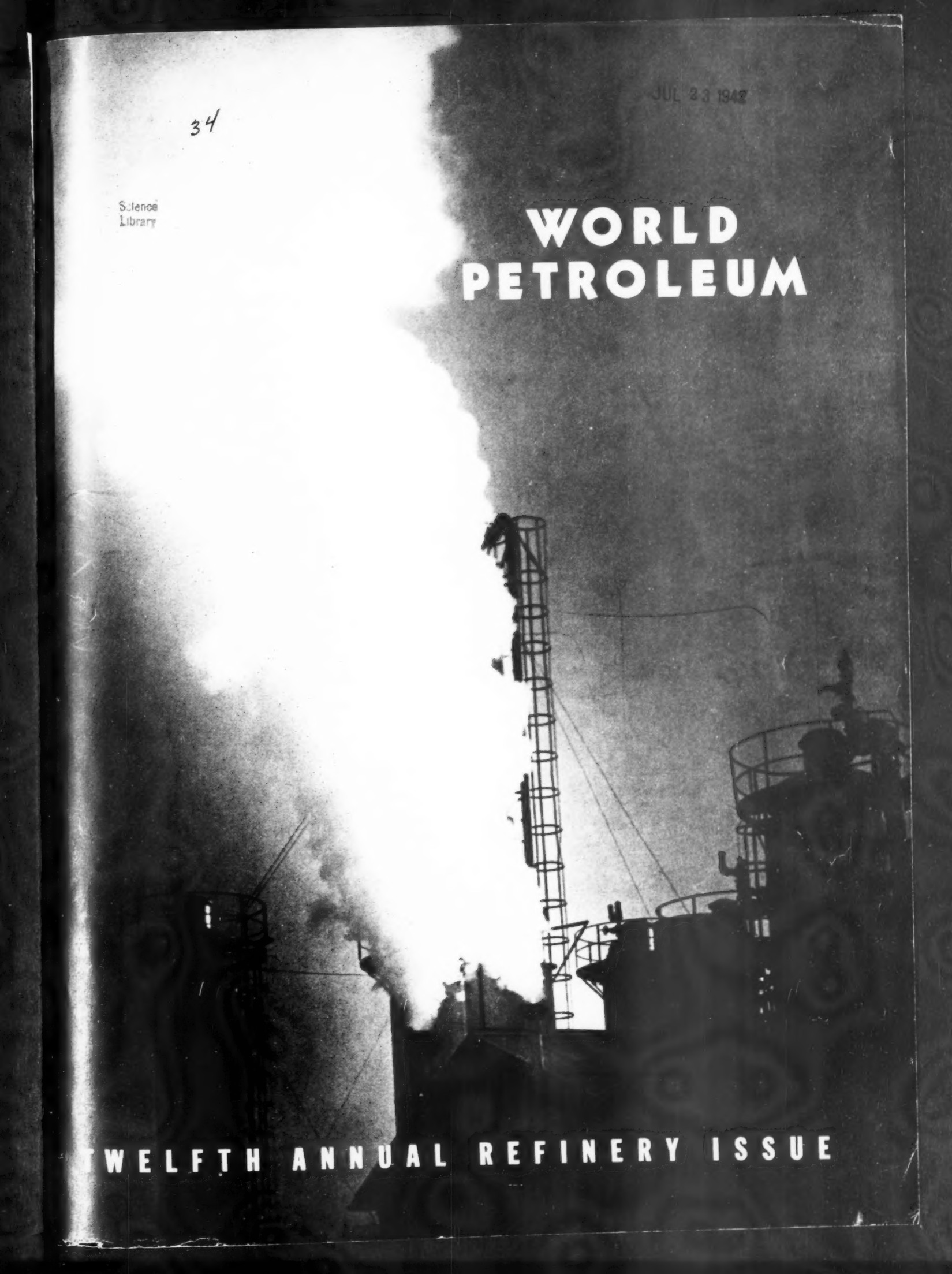

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THE MANAGEMENT PUBLICATION OF THE INTERNATIONAL PETROLEUM INDUSTRY

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High pressure gas separator in a modern Gulf Coast refinery: embodying units for natural gasoline stabilization, thermal cracking, polymerization and alkylation, this plant, completed in the latter part of 1941 fits perfectly into the war production program. Photographed for World Petroleum by Ulric Meisel.

EDITORIAL

GOVERNMENT-INDUSTRY COOPERATION FACES NEW PROBLEMS

TRANSFORMATION of the oil industry of the United States to an essential war industry represents a triumph of team work between industry and government. To the success of this partnership the industry has contributed its highly developed resources which have been kept steadily in advance of expanding commercial demands; its patents and processes, worked out through long and costly experimentation, for the production of materials vital to successful military operations; its capital, trained personnel and the technical knowledge requisite for the construction and operation of new plants or the adaptation of existing structures to new uses. The government for its part has been able to advise the industry regarding the products and quantities required for war purposes; has obtained the waiver of legal prohibition against cooperative action, the pooling of resources, exchange of products and joint use of facilities; has assisted in obtaining materials for construction of plants to turn out products required solely for war use, and has extended financial assistance for the erection of such plants where necessary.

In the attainment of its primary objectives the arrangement has been highly effective. It has succeeded because Secretary of the Interior Ickes as the representative of the government in the highly responsible post of Petroleum Coordinator had the vision and sound common sense to recognize that the complicated task of supplying a great war machine with a wide diversity of specialized products for the making of munitions, and the propulsion of planes and ships and tanks and other vehicles of war could best be directed by men of practical experience and technical skill. He built up a staff drawn from the ranks of the oil industry and related industries to conduct the operating and advisory work of his agency. No less essential to the successful functioning of the team, as the Coordinator himself has testified on numerous occasions, has been the zeal with which members of the oil industry have devoted their energies to the supreme task of winning the war, meeting new and unanticipated demands as they arose without question as to the effect upon their own business or as to how the heavy losses involved were to be compensated.

While the attainments of this joint effort of industry and government in meeting direct war demands despite the rapid increase in their dimensions give ground for congratulations on the part of the nation other developments in the war situation have raised knotty questions which may endanger the future effectiveness of the partnership unless adequate solutions can be found. Most of these pertain to matters over which the OPC has no direct authority and on which it can only make recommendations to other governmental agencies which may not have an equal appreciation of the oil industry's vital relationship to successful prosecution of the war. A case in point is the penalty of a million dollars a day which the oil companies have had to pay because of the forced change from sea to land transportation in the movement of petroleum from the Gulf Coast to the Atlantic Seaboard under a price ceiling imposed by the Office of Price Administration. Recent price advances authorized in the eastern area do not remove the difficulty because they do not apply to heavy fuel oils which are most important to the war program.

Another economic complication arises from the necessity of changing refinery operations to produce more low priced fuel oil and less of the established "money product," gasoline, so that refiners are under the necessity of taking a loss of $160. on every tank car of fuel oil delivered to the Atlantic Coast. Still others are presented by the need for increasing the production of certain types of crude which can be done only by using materials controlled by the War Production Board and by inequities imposed upon producers and refiners through the fact that in order to meet war requirements for certain products there is an unavoidable output of other products for which no market or perhaps no means of transportation can be provided. The prospect of an early imposition of nation wide restrictions upon the use of automobiles as a means of saving rubber presages another set of difficult problems.

No special incentive is needed to induce the oil industry to exert every effort that can be employed to keep the nation's war program moving at top speed. Oil men are concentrating their energies upon this one main purpose and in so doing are incurring losses which if long continued will cripple the industry's ability to serve effectively now and hereafter. As Coordinator Ickes forcefully told a House committee at a public hearing upon the Connolly-Steagall bill no other industry is being asked to supply an essential war material below its costs and if oil companies are compelled to do so not even those that are strongest financially will be able to stand the drain as long as the war is likely to last. It is in preventing the impairment of the industry's efficiency by factors beyond its own control that the severest tests of the relationship are likely to be met.

AMERICAN REFINING Becomes a War Industry

Keeping Pace with Tremendous Growth in Military Demand Plant Facilities are Being Provided to Supply Aviation Fuel, Explosives, Chemicals and Artificial Rubber to Meet the Needs of the United Nations.

IN the transformation of the refining activities of the United States to a virtually complete war footing the industry has passed through three distinct phases. First of these was the national defense period when the first steps were taken toward expanding the armed forces of the country and increasing the supply of materials needed for their use. Its objective was limited to improving the nation's ability to resist possible attack. The second step was taken when America assumed the role of the arsenal of democracy and undertook the task of supplying arms, food and other materials under the lend-lease program. The third and vitally important chapter opened with the Japanese attack on Hawaii.

With the adoption of plans for a larger navy, a moderately expanded army and a substantial increase in the air arms of both forces it was recognized that an essential part of this program was provision of arms and armament, planes and tanks and other necessary material and equipment. To aid in the solution of the problems of supply an Advisory Defense Commission was set up in June 1940 by order of the President. Oil was allotted a place in the picture through the appointment of a special Petroleum Advisor, a position ably filled by Dr. R. E. Wilson. With a small staff of assistants and with the cooperation of the oil industry itself, the Petroleum Advisor instituted a survey to determine the extent of United States supplies of materials suited to military use and of the facilities for converting these materials into the specialized products needed for the equipment of the Army and Navy. It was found that some forty refineries were in a position to produce aviation fuel, a term which then included everything of 87 octane or higher. Actual production of this high test fuel was in excess of current demand and stocks were gradually rising, having reached 4,000,000 bbl. at that time representing a year's production from facilities then in existence.

Among the recommendations of the Commission in regard to petroleum was one that productive capacity for aviation fuel be increased 50 percent. It was the opinion of the military authorities that such an increase in output, coupled with the accumulation of a six months supply in storage, would be sufficient for prospective needs. When the President's suggestion that the production of planes might ultimately reach 50,000 a year it was estimated that such an output, if ever obtained, might call for an added 10,000,000 bbl. per year of aviation gasoline or a virtual doubling of the current production. The figures seem far from impressive in the light of later developments but it must be remembered that the program envisaged at that time was one of preparation to resist a possible attack on our shores.

Although the plan for the purchase and storage by the government of a six months supply of high octane gasoline was not carried out immediately a number of oil companies of their own volition moved to construct 100 octane units in anticipation of future needs, a fortunate circumstance as subsequent events proved.

Other plans worked out during the term of the Advisory Defense Commission which later was succeeded by the Office of Production Management provided for a large increase in storage facilities at strategic points, for the production of war materials such as toluene and various chemicals and for the construction of cross country pipe lines. While not all of these plans were put into operation the oil industry was definitely started on the way to becoming an essential factor in the preparedness plan while the research organizations and engineering staffs of the oil companies turned their thinking toward the development of new means and facilities for serving the national defense through production of war materials.

Adoption of the lend-lease law in April 1941 committed the United States to the supply of food, munitions and other tools of war to the nations that were contending against the totalitarian powers. Since these materials were to be supplied on credit the demand quickly rose to several times the quantities that these countries had been able to acquire when each order had to be paid for on delivery. One of the products urgently needed by all the allied nations was aviation fuel and it quickly became evident that to satisfy their requirements in addition to those of the program set up by the United States for its own defense would necessitate a further expansion of American facilities for the manufacture of this and other specialized war materials.

To obtain the steel and other materials required for refinery construction on a large scale, to eliminate avoidable duplication of transportation and other services and particularly to enable oil companies to pool their products and facilities where such action would contribute to more efficient operation (which the companies were forbidden to do of their own initiative by the antitrust laws) it was felt in official circles that the authority of the federal government should be put behind the oil industry particularly to eliminate some of the legislative obstacles.

Accordingly, on May 28, 1941, one day after his declaration of the existence of an unlimited emergency, the President established the Office of Petroleum Coordinator for National Defense and appointed Secretary of the Interior, Harold L. Ickes, as its executive head. In explanation of his action the President said in the course of a letter addressed to the Petroleum Coordinator: "One of the essential requirements of the national defense program, which must be made the basis of our petroleum defense policy in the unlimited national emergency declared on May 27, 1941, is the development and utilization with maximum efficiency of our petroleum resources and our facilities, present and future, for making petroleum and petroleum products available, adequately and continuously, in the proper forms, at the proper places and at reasonable prices to meet military and civilian needs."

As a guide to the Coordinator in the administration of his office the President said in another passage from the same letter: "It is expected that you will consult with the petroleum industry and those industries which affect its functioning, to aid them in shaping their policies and operations in the discovery, development, production, processing, transportation, storage, distribution, marketing, consumption, and import and export of petroleum and petroleum products."

Although the establishment of this federal agency came as a surprise to the oil industry its members promptly rallied to the support of the Petroleum Coordinator and proceeded to put into effect the recommendations which came from his office as soon as the preliminary work of selecting a staff and setting up an organization was completed. Four main divisions were originally established to deal with the four chief activities of production, refining, transportation and marketing. At the head of the Division of Refining was placed Wright W. Gary, an engineer of broad experience in refinery design and operation as well as in actual plant operation.

Phillip M. Robinson, who had served under Dr. R. E. Wilson in the petroleum work of the O.P.M., was selected by Mr. Gary as one Assistant Director, and R. B. Cragin, who has ably directed the supply section which has been instrumental in "stretching" the productive capacity of existing 100-octane units, was selected as the other Assistant Director. From the beginning the responsibilities of the Refining Division have been particularly great because of the heavy and urgent demands coming from many parts of the world for specialized forms of fuel and lubricants to supply and operate the machines of war. In order to appraise the situation accurately it was necessary to make a fresh survey of refining capacity and to determine what quantities could be manufactured of the products particularly in demand. The information thus obtained had then to be compared with the estimates of national and international agencies as to their anticipated requirements. As a net result of this inquiry it was found that existing capacity for the provision of certain products was inadequate to supply the full

Opposite, Wright W. Gary, Director of the Division of Refining, Office of the Petroleum Coordinator, under whose direction the refining industry is being transformed from peacetime to war time objectives; photo by Universal Press. Below, Standard of Louisiana's recently completed plant yielding raw material for butyl rubber.

demand then developing. The danger of a coming shortage was particularly acute in respect to aviation fuel although stocks on hand were larger than they had been at any previous date. By this time aviation fuel had come to mean in the minds of military men gasoline of 100 octane as experience had shown that nothing less would provide the extra speed, pick-up and maneuverability needed for aerial combat. Improvements in design and construction resulted in the equipment of new planes with engines that would not operate efficiently on fuel of lower quality.

To this task of stepping up the supply of aviation fuel the Refining Division of the Coordinator's Office immediately addressed itself. One of the first requests directed to the petroleum industry by Coordinator Ickes was for a doubling of the output of this product and shortly afterward the goal was moved upward to a trebling of production. To get action with the least possible delay every manufacturer of 100 octane gasoline with his staff of technical experts was called in to determine what could be done quickly to expand production. The problem could not be solved by new construction alone, because of the time lag, but it involved such questions as getting supplies of suitable base stocks, utilizing surplus light end products from refiners who were not themselves making use of them and modifying engineering specifications to aid building operations by conserving critical materials. The oil companies themselves presented plans for the installation of new units capable of providing an increase of 100 percent in production, using light products that were in the main readily available.

To make possible a further increase in output of this all-important material it was necessary to look about and discover where additional facilities could be set up to make use of crudes suitable for base stocks and to enlarge the supply of blending agents. This survey revealed that the output of aviation fuel, because of the very limited demand, was much below actual capacity. According to the estimate prepared it was possible, through full use of available raw materials, to bring production up to three times the 1940 average though this involved some risk of denuding commercial gasoline of part of the volatility that had come to be accepted as an essential characteristic. This finding forced a study of methods for putting more materials into the class of 100 octane constituents through processes already known and established. While aviation fuel easily took first place among the subjects demanding the attention of the Refining Division during its early period of operation other problems were not ignored. One of these was the provision of toluene for use in the manufacture of explosives. Contracts for the construction of large units to be devoted to its production were placed. Arrangements for the erection of four plants to manufacture synthetic rubber also were concluded. The business side of this arrangement was handled by the Rubber Reserve Corporation but the Office of Petroleum Coordinator participated in it because the raw material to be used in the making of synthetic rubber was butadiene, a petroleum product. It is worth noting that a much larger rubber program had been recommended by the National Defense Advisory Commission in 1940, but the decision of the officials in charge of government financing was that four plants with a combined capacity of 40,000 tons would be sufficient for the time since shipments of natural rubber were coming forward regularly with no visible signs of early interruption.

Some of the units in one of the principal U. S. refining centers; here toluene, aviation gasoline, and other war products have been produced for some time in ever increasing quantities. It is expected that substantial yields of butadiene will soon be available from this plant.

Getting the construction of these new plants under way involved a mass of detailed work on the part of the Petroleum Coordinator's staff as well as by the engineers of the oil companies and the construction firms carrying on the work. Included in these activities was the checking of design, the obtaining of priorities for restricted metals, conference with representatives of the Army and Navy as to their requirements and with the administrators of Lend-Lease as to products needed for shipment to other countries, and consultations with the government's financial agencies such as the Reconstruction Finance Corporation and the Treasury Department in cases where loans were under consideration for the construction of new plants. As a result of the coordination effected between the oil industry and the various agencies of government concerned with the movement for national preparedness and assistance to countries aligned against the totalitarian powers, this work was effectively organized during the six months following the establishment of the Petroleum Coordinator's Office. The 100 octane program was well ahead of current demands; surveys had been made to determine capacities and potential increases from existing facilities; plant expansion projects involving an expenditure of $150,000,000 were in process—some actually building and others in the blue print stage; the Supply Priorities and Allocations Board had approved the Coordinator's request for A-1-a ratings on plants producing war materials; owners of patented processes had agreed to a 50 percent reduction in royalties and the members of the oil industry were working in close cooperation with the Coordinator's organization in all these undertakings.

To spur on the planning of new facilities for 100 octane gasoline a "New Facilities Section" was created in November, 1941. In addition to giving searching consideration to the technical and economic details of the various new projects and negotiating in behalf of the Government to determine fair prices for the product, this group developed the full details of the necessary contracts and steered the prospective contractors through the mazes of official Washington to the RFC subsidiaries who were authorized to purchase the product and lend aid in plant financing.

The technical and economic phases of this work were handled under D. W. Wilson, Refining Director, District I, assisted by a staff of aviation gasoline experts largely drafted from industry on a temporary basis. The negotiational work required men experienced in both law and refinery terminology. These, too, were "drafted," largely from the industry's ablest patent attorneys whose scientific training made them useful for the work.

Descent of the Japanese in treacherous attack on Pearl Harbor on December 7 changed the picture completely. By making the United States an active participant in the world conflict it vastly increased the demands upon the nation's industries and rendered all previous calculations obsolete. Up to that time the objective had been to satisfy lend-lease demands and the country's own military needs without material disturbance to the usual commercial operations of industry. With the coming of all-out war, an all-out transformation of industry to meet war demands was recognized as imperative regardless of its effect on ordinary business. Goals previously set for production were forgotten before the necessity of attaining maximum output of guns, munitions, ships, planes, tanks and fuel. Along with the task of fueling the greatest air fleet ever assembled, an array of fighting ships and cargo vessels larger than ever before contemplated and the mechanized equipment required for transport of great armies the United States still had to carry the burden of supplying aviation gasoline, fuel oil and lubricants to the nations allied with it in the world struggle against totalitarianism.

Fortunately for the cause of the United Nations the American oil industry, through the work and planning already done was in a good position to cope with the tremendous added responsibility placed upon it. On the day following the first Japanese onslaught the representatives of the oil industry gathered in Washington in response to a summons previously issued by Coordinator Ickes and were able to proceed at once to the organization of the industry on a full war basis. The Petroleum Industry War Council was organized to mobilize the country's oil resources for full effectiveness in the prosecution of the war. Being on the ground they were able to confer promptly with the members of the Coordinator's Refining Division on the new problems presented by the sudden change in the situation. These problems were many and complex. The plans and procedures earlier agreed upon were still applicable to the meeting of increased demands as indicated by the fact that the first contract for additional plant construction was signed within five days after the Japanese attack. In carrying forward the new program of expansion however, new factors had to be taken into consideration. In the earlier stages of expansion of 100 octane, toluene and butadiene production the provision of new facilities was undertaken for the most part by companies that had available from their own operations the light elements needed for the manufacture of high test aviation fuel and of the alkylate and other blending agents entering into it. These same companies, naturally enough, were the ones that had extensive plant facilities to which new units could readily be added and technical staffs for their operation.

This explains one of the criticisms earlier voiced regarding the petroleum war program, namely, that contracts for war material plants were in most instances assigned to major companies and that the small independent concerns did not have an opportunity to participate in this activity. The explanation of course is that the larger companies as already mentioned were the ones that had the required materials, the plant equipment, the technical knowledge and the financial resources needed for the prompt initiation of the construction of 100 octane gasoline, alkylation, toluene and butadiene plants. In the rush to get a rapid increase in the output of such products it was necessary in the early stages of the preparedness program to call on those who were in the most favorable position to supply them.

Plans of the Refining Division of the Coordinator's Office, however, did not overlook the utilization of the smaller refineries in the production of war materials. Even before the declaration of war in December the Division staff had been working out plans for combination plants in which the light products of these smaller establishments could be used in swelling the ouput of supplies for the war machine. The incentive for bringing into the program all possible sources of supply was of course increased by America's full-fledged participation in the war as an active combatant and a considerable number of projects were approved for the erection of cooperative plants which will draw their materials from a group of nearby refineries or for the purchase of materials available within a certain area by one company which would then be justified in undertaking the production of 100 octane gasoline. In the program, as finally developed, nineteen major companies and thirty-one independent oil companies are actively participating. Since mid-January the capacity under contract has been trebled. Production has risen 50 percent above the maximum estimated a few months ago.

To facilitate such undertakings for increasing the output of products for which there might be small demand after the war several plans for government financing were worked out. In the case of a company which has or can obtain sufficient funds for construction of a plant this may take the form of a contract with the Defense Supplies Corporation by which the Corporation agrees to purchase the output at a specified price designed to yield a modest return on the investment. In order to be eligible for such contract the oil company must submit its plans and cost figures for approval by the Refining Division of the Coordinator's Office and after it has passed this test the OPC undertakes to obtain clearance for the project from the War Production Board which automatically conveys the right to A-1-a priority on materials for construction. Revision of the sales contract in accordance with changes in raw material prices is provided for.

If a refiner is in need of a loan in order to erect a projected plant the Reconstruction Finance Corporation through its subsidiary Defense Supplies Corporation will advance up to 75 percent of the total cost after the plans and cost estimates have received the approval of the Refining Division. A similar contract for the purchase of

output is made for a period of three years with an option to the government agency to renew it for two successive yearly periods, the purpose being to have it cover the duration of the war. Under a third plan the government itself will build the plant and lease it back at a fixed rental to the refinery who then executes an agreement for sale of his product to the government. At the end of the contract period the plant remains the property of the government which can dispose of it in such manner as it deems fit. This plan is devised especially for small operators or groups who may wish to pool their resources without assuming responsibility for operation of a plant beyond the period of the emergency. It has been applied also in contracts for butadiene plants which face an uncertain future with a likelihood that they might be unable to operate commercially after the war.

Paving the way for the construction of plants through government financing is only one of numerous ways in which the Refining Division has aided the oil industry in mobilizing its facilities for war service. The signing of a contract is only a first step, though of course a necessary one, toward the actual production of needed materials. Since the plant is to turn out supplies essential to military operations it receives a top line priority rating of A-1-a once it is approved by the War Production Board. But with shipbuilders, airplane manufacturers, fabricators of tanks and guns and other implements of war all demanding steel and other metals in greater and greater quantity; with these demands all deserving immediate fulfilment, it may, and frequently does, occur that a long lapse intervenes between issuance of a priority and delivery of the materials it covers. Before every official in Washington who has to do with production activities is a list of what are designated as critical materials which means that they must be used as sparingly as possible. In the erection of a refining plant where equipment of many kinds is called for, reduction in the use of these critical materials to a minimum may lead to a material saving in cost and, more important still, in time spent on construction. One of the useful functions of the Refining Division is to find ways in which such savings of time and materials can be accomplished.

In the earlier months of OPC operation it was found that delays in plant construction resulted in many cases from lack of coordination in deliveries. Progress on an entire unit sometimes was held up by lack of some relatively small but essential piece of equipment. To deal with this situation a special construction section was organized as part of the Refining Division. Its function is to allot the fabrication of parts in such order that their delivery date will coincide with the time when they are needed. Beyond this the staff of this section, which is headed by Max B. Miller, well known designer and builder of plants, is constantly engaged in devising, collecting and transmitting to constructors new ideas in time saving and labor saving methods and short cuts in construction and operation in an effort to attain peak efficiency in bringing new plants into operation in the shortest possible time.

In another direction an important step toward the more effective utilization of effort and materials has been taken by the projection of combination units. Since the petroleum products most in demand for war purposes are derived mainly from the light ends of the refining process there appears to be no reason why single plants could not be built to produce two or more of these materials instead of erecting costly structures to supply each one. Engineers of the Refining Division developed a basic design for such combination units and the technical staffs of various oil companies have made important contributions to the furtherance of the idea.

One of the most important results of the relationship which Secretary Ickes has described as the partnership between the government and the oil industry, has been the pooling of effort, the interchange of ideas and technical knowledge among members of the industry that has been fostered diligently by the OPC. This is something that the oil industry could not do of its own initiative because of the stringent legal prohibitions against combinations or agreements affecting trade. It was early recognized, however, that for effective war activity the pooling or interchange of efforts, products and processes was of first importance. One of the first steps taken by Secretary Ickes after his appointment as Petroleum Coordinator was to obtain assurance from the Department of Justice that such united effort, wherever it contributed to the prosecution of the war, would not be made the basis of legal action against the companies participating. Without waiting for Congress to give this assurance the binding force of an enactment of its own, which it tardily did a few weeks ago, the oil companies proceeded without hesitation to do whatever was asked of them in this direction because of the compelling needs of the situation.

Cooperative action was applied first of all to the pooling of products and elimination of duplication in the movement of oil where it effected economies in transportation. Pooling of ideas came later when individual companies released to other members of the industry processes which they had developed for their own use and agreed to an interchange of technical data that made possible the most effective use of the industry's whole store of technical information. This important line of activity is being carried forward by the Processes Development section of the Refining Division of OPC under the direction of Cary R. Wagner.

One of the most difficult problems in connection with the transformation of the refining business to a war footing has been to provide the required materials for military use where they were most needed without completely disrupting the operations of the oil industry in catering to civilian demand. This problem has been accentuated by the transportation crisis which forced a drastic cut in the petroleum supply of the great industrial region of the eastern states. Despite this reduction in the eastward flow it was necessary to keep crude going to eastern refineries to enable them to go on turning out war materials for which they had contracted and at the same time to supply commercial gasoline and fuel oil for the maintenance of essential activities and for the operation of industrial plants engaged in the manufacture of military supplies. At the other end of the line, along the Gulf Coast and in the Mid-Continent, where the withdrawal of tankers led to an accumulation of stocks that quickly threatened to overrun storage equipment, the problem became one of restricting both production and refining without injury to the war effort. On the side of production it was desirable from a military viewpoint to stimulate the output of crudes especially suited to high yields of base stocks for use in the manufacture of high octane gasoline, but in a business as highly competitive as oil there are obvious difficulties in encouraging full production from one group of fields while others nearby are asked to cut below their ordinary proration allowance.

Similarly, where refinery output of the customary range of products is above the capacity of available transportation facilities to move them, the logical course is to close down some refineries and to concentrate operations within the remainder. The decision as to which shall close and which continue, no matter how carefully arrived at, is likely to be regarded as dictatorial by some of those affected. Stern necessity, however, is forcing the classification of Gulf refineries according to their relation to the war effort into those that are engaged in the production of 100 octane gasoline or other military necessities; those that can produce high test gasoline for aviation training, those that are working to meet lease-lend demands, and all others. The latter classification includes plants that have been or may be forced to suspend operations, but meanwhile provision is being made to protect their owners against loss through such action and to transfer the supplies of shutdown plants to others that continue in operation. The operating program must be continually adjusted to the available means of transportation and even with all efforts to accomplish this, economic unbalance cannot be entirely avoided. The operating program of the Refining Division is administered by an operation Section headed by Douglas P. Bailey.

In view of the almost limitless opportunities for difference of opinion as to essential requirements and methods of procedure as well as for charges of bias or favoritism in decisions that have to be made under the stern compulsion of war the work of the Refining Division of the OPC has proceeded smoothly, rapidly and with a steadily increasing degree of efficiency. Much of the credit for this favorable state of affairs is due to Director Gary and the highly capable staff he has drafted from the ranks of the oil industry. Con-

fidence of the oil industry's members in the ability and character of these men is an important factor in this condition while the geniality and inexhaustible patience of Director Gary himself contributes to the smoothing out of such difficulties as do arise. Members of the Refining Division are themselves the first to point out, however, that the achievements that have been reached would have been impossible except for the readiness and enthusiasm with which the oil industry itself has put its resources at the nation's disposal and has exerted its every effort to make certain that so far as petroleum is concerned the materials of ultimate victory shall be provided in whatever amount needed, wherever needed and at the time when they are needed. This has involved not only the investment of huge sums in the provision of war facilities but also the sacrifice in many instances of profitable commercial operations and the acceptance of heavy losses in order to maintain established services for the convenience of the public. Through its own organization under the leadership of the Petroleum Industry War Council, through the regional committee appointed by Secretary Ickes from the ranks of the industry and through the leadership and cooperation of the OPC itself a form of team work has been developed that has made it possible to overcome obstacles that otherwise would have been unsurmountable. The result is an outstanding achievement the full details of which can be told only after victory has come.

From the experience already gained since it started its transformation to a war footing, through the concentration of its research organizations on immediate war problems and through the plans worked out by the refining Division of the OPC the oil industry itself has learned much regarding the requirements of the greatest war machine ever constructed and as to the most efficient application of its resources to satisfying those requirements. As evidence of the industry's readiness to sacrifice all other considerations to the demands of the war program the Refining Division of the OPC now has on hand more proposals for war projects than it has authorizations to build. This does not mean that the limits of wartime demand have been reached but only that the industry itself is in advance of the available supply of materials for construction. New projects will be put under way as it becomes possible to do so. Nobody yet has attempted to define the ultimate demands of a war that extends to every quarter of the globe. Aside from that consideration provision must be made against possible sinkings, bombings of plants and stores and other losses. Moreover there is a world wide problem of ferrying men and equipment which is assuming steadily growing proportions. To what extent the further concentration of American refining on war production may go it is impossible to foretell but it can be said with assurance that whatever the demands the oil industry will be ready to meet them as fast as the means of construction and transportation can be supplied.

Details of a modern refinery in the south. With large refining capacity and limited materials for new construction the petroleum industry faces the problem of integrating the three main programs for production of aviation fuel, toluene and butadiene. Photos by Ulric Meisel.

REFINERY Yield Changes in War Time

By John D. Gill

Increased Production of Fuel Oil at Expense of Gasoline Output Imposes Heavy Losses Which Call for Adjustment — Problem Has Complexities but Is Not Insoluble.

DETERMINATION of the reasons for the equated yields of heavy fuel oil and motor gasoline from crude oil at any moment in recent decades presents one of the prettiest problems in petroleum economics. It is a highly complicated matter. The mere presentation of the problem raises the question: Why make heavy fuel oil at all at realizations usually less than the cost of the delivered raw material when the art of the industry is such that all components of crude oil could be converted to motor fuel bringing realizations substantially above the delivered cost of the raw material? Like many other complicated economic problems, determination of the percentage yield of fuel oil at any moment is left to the practical integration by hundreds of units of the industry of many factors including: (a) costs of converting heavy fuel oil to gasoline; (b) the value of heavy fuel oil in relation to competitive fuels and to gasoline; (c) the current and prospective cost of production of crude oil and, (d) the probable extent of the future supply of crude oil. Clearly, radical changes in any of these major factors would alter the percentage yields of fuel oil and motor fuel.

For example, if the cost of crude production declined and the supply of crude oil appeared limitless, the yield of fuel oil might be expected to increase; vice versa, if the cost of crude rose or if a shortage of it appeared imminent, the yield of fuel oil might be expected to decline. Actually, the yield of fuel oil has declined over the years. There was a time when it exceeded 50 percent. In the decade and a half since 1927, it has decreased from 36.6 percent to less than 25 percent, in response to the urge to conserve crude oil and to utilize the developing art of converting heavy fuel oils to automotive fuels. During the past fifteen years, the history of yields, country-wide, of the four principal products together with the resultant effect of changes in yields, operating costs and capital requirements upon unit values, and the derived ratio of the unit value of each of the major products to the average unit value of all products are presented in Charts I to IV inclusive on this and the following pages.

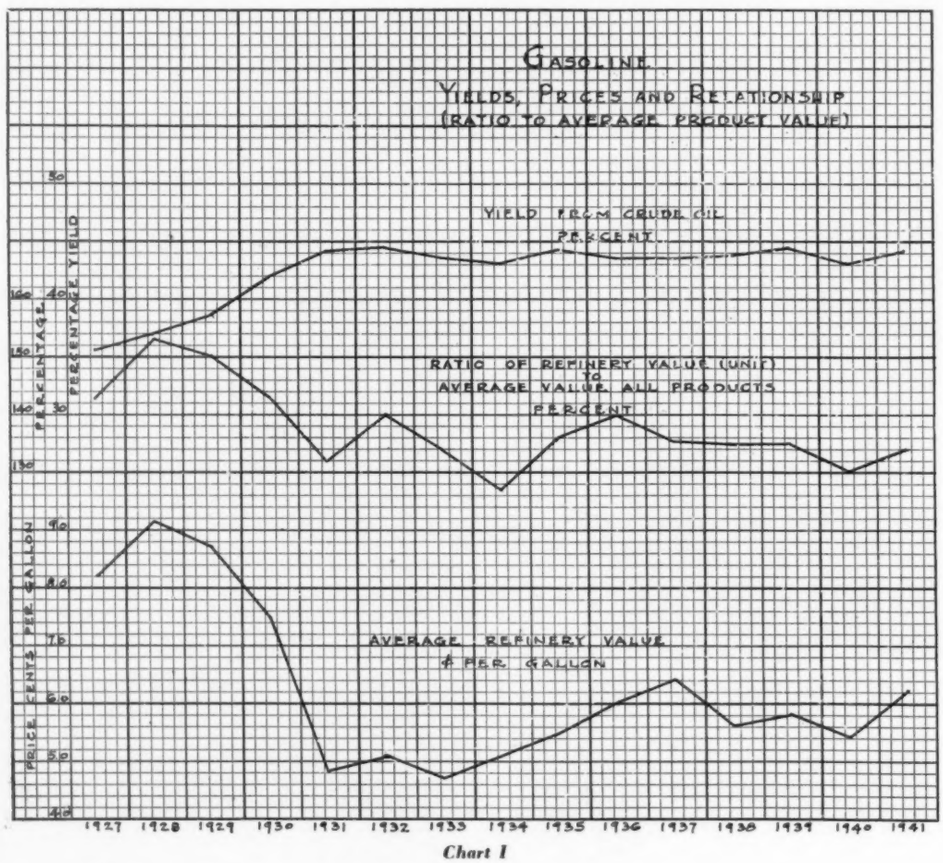


Chart I

It may be assumed from the declining trend of the percentage yield of residual or heavy fuel oil that refiners have found it advantageous to retreat as rapidly and as far away as possible from the competition which other fuels, notably coal, offered to their own chief byproduct. True, over a long period, and due to the rapidly expanding demand for gasoline and some other petroleum products, the industry has made larger absolute quantities of heavy fuel oil. But the significant fact is that it made less and less of this material with respect to total output. The main reason for this changing relationship will appear clearly from an examination of Chart IV. Sometimes, the industry received for heavy fuel oil only 30 percent as much as it received for the average of all products and rarely ever did it receive as much as 50 per cent. There has been very little incentive to make heavy fuel oil. On the other hand, as shown by Chart I, the production of gasoline has been favored because even in the earlier years of the period presented realizations for gasoline approximated 150 percent of the average realizations for all products and only in one year of the period did gasoline realizations fall to as low as 130 percent of the average. Prior to 1927, gasoline was still more favored than in the period under immediate review.

It will also be observed from the charts that, over the period since 1926 (a somewhat longer period would portray the changing relationships even more strikingly) the price of gasoline has declined substantially while the price of residual fuel oil has moved nearly sidewise, being actually as high in 1940 as it was in 1928 and a trifle higher in 1941 than in 1929. It may be said that always the price of gasoline has been subject to all of the refining technological advances made within the industry. That is, the public has received the benefit of these advances through the price declines indicated by the data of Chart I. Now the price structure of the products of petroleum, that is, the absolute prices of the individual finished components of the raw material and their inter-relationships, are clearly dependent upon several factors: the price of competitive materials; the extent of their existence in the raw material; the cost of producing virgin yields of them; and the cost to convert raw material most suitable for one product into an entirely different product. Each product contributes a share of the total gross income of the refining

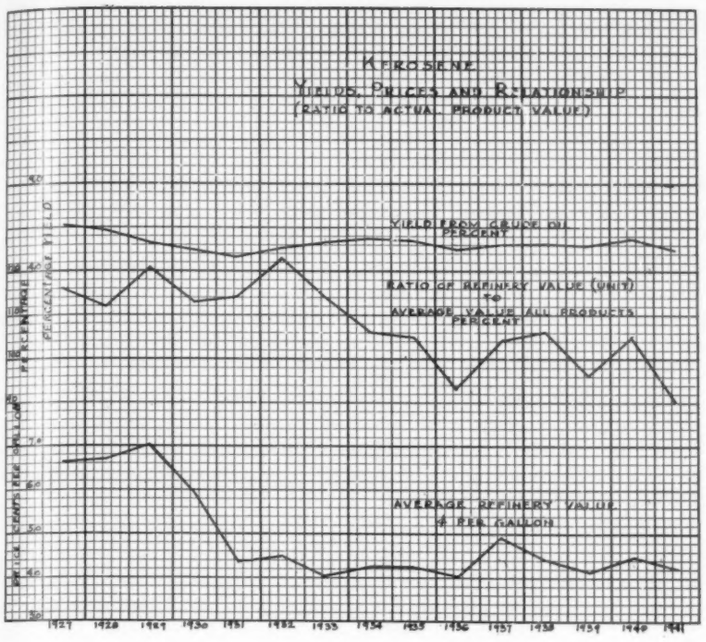


Chart II

industry, which in the aggregate equals the delivered cost of raw materials, operating costs, fixed charges, overheads and earnings expressed algebraically. The contributions of the several products are presented in Chart VI. It will be seen from an examination of the chart that, for years, gasoline has been contributing approximately 60 percent of the total gross refinery income while residual fuel oil has provided only about 12 per cent. Gasoline has contributed, gallon for gallon, more than three times as much as heavy fuel oil and on a gross dollar basis five times as much. Chart VI shows for the United States refining industry the variations from year to year in the dollar per barrel contribution of each of the major product groups to the refiner's gross income from refining (packaging, etc., omitted).

In the light of the facts just stated, it must be very clear that a change in the percentage yields of the several products is likely to make a change in the refiner's gross income. If the change is the relatively simple, but important, one recently imposed upon the industry, namely, of raising the gravity and percentage yield of heavy fuel oil and lowering the percentage yield of gasoline, the effect upon the refiner's income is profound. Thereby a set of conditions suited to financially satisfactory operations is replaced by a set of conditions which results not only in a decline of earnings but in actual monetary losses. If, for example, the yield of gasoline is reduced by 20 percent and the yield of fuel oil increased by a corresponding absolute volume as shown by the unconnected termini of the dotted lines of Chart V, the effect upon gross income at constant prices is that shown by the unconnected termini of the dotted lines of Chart VI. The decline in overall income in this instance is 15 cents per barrel. Percentagewise, a reduction of 15 cents per barrel represents a decline in gross income of only 7.6 percent. To the uninitiated, this may seem inconsequential. But the refining branch of the industry ordinarily works on very narrow margins. For its entire service, the refining division receives net, after all costs and charges, on the average only about one-sixth of a cent for each gallon of products it produces. For all that it does it charges the public only about one cent per gallon, that is, for the use of, and wear and tear on, equipment employed in the refining process and for all its out-of-pocket expenditures for labor, fuel, utilities, chemicals, supplies and maintenance materials. Of course, there is no basis for comparison of this expenditure with a standard set-up for industry performance. However, on an absolute cost basis, and in the light of the intrinsic values incorporated into products by the refining process, it seems like a very modest amount. There was a time not many decades ago when the industry had to charge from three to four times that much for its service. The current level of total charges is the result of continuous, measurable technological improvements.

Even the small measure of return on investment mentioned in the preceding paragraph is dependent upon close attention to costs and yields. When yields of the more valuable products decline, earnings suffer. This fact was recognized and clearly stated by Mr. Ralph K. Davies, Deputy Petroleum Coordinator, when on May 26 last he stated to the Oil Subcommittee of the Committee on Interstate and Foreign commerce of the House of Representatives: "In order to obtain greater volumes of fuel oil and lesser volumes of gasoline, the Government has found it necessary to direct that changes in normal refining practices be made which will accomplish a different yield of various products from a barrel of crude in certain areas. This, in effect, has meant for the refiner that he convert gasoline into fuel oil. The operating procedure is not quite so simple but the effect is precisely that. High valued products are debased and to this extent values are destroyed."

As stated earlier in this article, at any given moment the price structure is predicated on a fairly well established set of relationships between the contributions of each product to the total income needed to cover the refiner's total charges. Any disturbance in one factor immediately creates the need for a change in one or more of the other factors. This should make it clear why, in an era of fixed ceiling prices, the ceiling price base period characterized by one set of yields is entirely unsuited as a ceiling price basis for another period characterized by an entirely different set of yields established arbitrarily by order, recommendation or directive issued to satisfy expeditiously some imperatively urgent demand. From the preceding statements, it may be understood that a change in yields no greater than that described may in one month cause a deterioration in the refiner's gross income equal to the average return on his investments in the refining branch of the business on two or three months of operations of average financial satisfactoriness.

Risking possibly boresome repetition of the principle involved for the sake of clarity: An eight percent return on net refining investment figures out to about seven cents per barrel of crude run to stills. Eight percent is as much as refiners make on the average although at times they have made more and, at other times, much less. It is an elementary fact, but one that appears to need restating and emphasis, that the profit of refiners is dependent on the yield structure set up under any particular price structure and the costs to produce those particular yields. The factors, of course, are to be measured simultaneously at any given state in the developing art of the industry. By processing crude oil the value of the raw material is increased by an amount equal to the difference between what is realized for products and

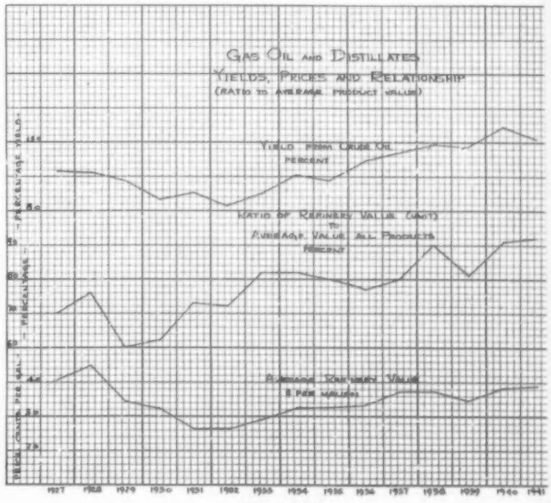


Chart III

the cost of the raw material. The lower the degree of fabrication in general, the lower the processing costs and, also, the lower the unit profit. But in the case of a refinery facilitated and organized for a low degree of fabrication the rate of return on investment may be as great as in cases of more elaborate processing which employ the most modern and varied equipment. By and

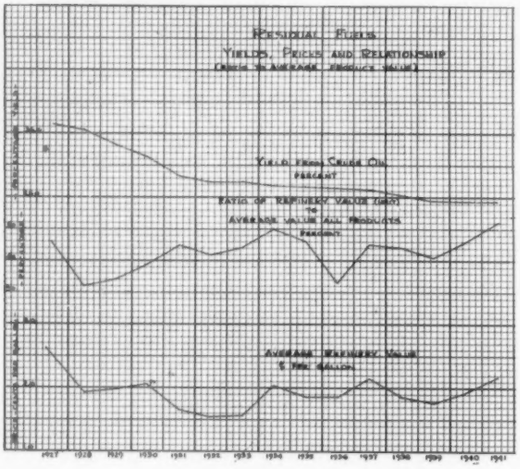


Chart IV

large, no product can be sold at less than the delivered price of the raw material plus operating expenses plus fixed charges and overhead plus profit unless the deficit represented by its lower than average value is offset by gains from products which sell at above the delivered price of crude plus operating expenses and so forth. Fuel oil and gasoline are illustrative. The former ordinarily sells below the average costs; the latter, above.

Consider a simple assumed case: If the delivered price of crude oil is $1.37 and processing 30 cents and profit seven cents the aggregate value of all products must equal $1.74. If the gasoline yield represents 50 percent of the crude and heavy fuel oil 50 percent (for simplicity's sake no loss assumed) and if the price of the first-named product is fixed so that it provides 65 percent of the needed $1.74, then the other product must of necessity be priced to return the other 35 percent. If the value of the gasoline is 65 percent of $1.74 or $1.13, when the price of gasoline is 5.38 cents a gallon, then the fuel oil must bring 35 percent of $1.74 or 61 cents which divided by 50 percent of 42 gallons or 21 gallons is 2.90 cents per gallon or $1.22 per barrel. If now, for any reason, at the current state of the art, the yield should be changed to 40 per cent gasoline and 60 percent fuel oil, the needed recovery from the value of products will still be $1.37 plus 30 cents (less a slight discount to allow for lessened cracking) plus seven cents or, very nearly as before, $1.74. Clearly if the price of fuel oil were fixed at $1.22, that product would provide 60 percent of 42 gallons times 2.9 cents or 73 cents and the gasoline portion of the barrel of products would have to provide the remainder of the $1.74 or $1.01 which would be covered by only 40 percent of 42 gallons or 16.8 gallons, equal to six cents per gallon.

Of course, this is a highly simplified, hypothetical case. Actually, the effect of a change of yields in the interest of satisfying the needs of the war economy is complicated if simultaneously with the change in yields of the major products other changes are made in refiners' crude processing by inclusion of production of essential war specialties for aviation gasoline, synthetic rubber, toluene and so on. The difficulties of analysis are increased by the unavailability of data on these newer processes—a direct resultant of inexperience. Nevertheless, for the determination of the main issue, these complications probably are relatively unimportant for the reason that the volume of specialties is very low and the changes in costs incurred on account of them is such a small proportion of total costs as to alter but little any conclusion based solely upon consideration of the fundamental yield changes.

Temporarily, the long march of progress of the refining branch of the industry to increase the intrinsic competitive value of the products of crude oil, that is, to make more of so-called superior products, is halted. But the revolutionary changes in the oil economy which have been expressed as a swing from a gasoline economy to a fuel oil economy by Mr. W. E. Perdew, who has performed a notable statistical research on the matter, and others, should be viewed in the light of the present emergency. The changes effected are simply a means of satisfying conditions created temporarily by a shortage of transportation. There being no ready way of curtailing fuel oil usage by industries essential to the war, and because of the transportation shortage, a reduction in refinery runs appeared to be a physical necessity in the refinery areas whose normal markets were affected by the transportation shortage: hence the change of yields to maintain at as high a point as practicable, the absolute output of heavy fuel oil. But because of the declining throughput even the substantial changes in yields whereby gasoline was stepped down and fuel oil stepped up, failed to provide sufficient fuel oil for essential purposes in this great market so that adjacent areas were also called upon to make more fuel oil relative to gasoline. Hence a change in yields is necessitated in all areas supplying the market along the Atlantic Seaboard normally served by deep-water transportation.

While simple hypothetical illustrations have been used for the purpose of presenting in briefest compass the principles involved in adjusting the price structure for arbitrary changes in yields of products, the matter is no academic one but rather constitutes an exceedingly practical problem taxing the competence of the affected branch of the industry and of the personnel of government agencies charged with maintaining the industry's wellbeing and effective performance in behalf of our industrial war effort and civilian requirements. An industry as important to the national economy as the refining industry cannot long suffer financial deterioration in the results of its operations without, sooner or later, experiencing disabilities in its sheer power to serve and, also, of long term importance, in its internal competitive structure. This structure is threatened by the differential effect upon the several units of the industry of the necessarily different degrees of compliance with any specific directive. The latter differences may be due to variations in contributions to the production of essential war products.

The loss of revenue resulting from a degrading change of yields of products must be compensated for by one means or another. Fortunately, the principles underlying corrective measures are well established. The relationships between price structures and changes of yields are comparatively simple. If relief is accorded through the medium of a price increase, it becomes clear immediately that the same price must apply to all producers and sellers operating in a given market. But obviously the effect of a uniform price increase upon these operators would be variable under conditions characterized by variations in performance stated above. This presents a not unsurmountable problem to be solved. On the other hand, if relief is considered by means of compensatory adjustments which are of necessity in the nature of definite dollar payments, the agency charged with administration of relief is immediately confronted with the virtual impossibility of acquiring accountancy precision in the measurement of the losses sustained. It appears clear that under these conditions relief by the very natural, proper, economic and desirable medium of price increases must be given first consideration. Very likely, at the current stage of relief administration, price increases to offset this type of burden would be readily embraced if the great burdens arising out of the high cost of tanker-substitute transportation, which patently are subject to precise dollar measurements, had been solved by the equally precise method of compensatory adjustment instead of by price increases.

The actual conditions present other problems to an agency charged with providing relief. But they are not insoluble. The problem of appraising the effects of the production of war essential products has been mentioned. Action should not be long delayed because of the present insolubility of this minor aspect of the problem. Then there is the further complication that losses incurred by certain refiners from a degrading change of yields has been in some measure offset by the acquisition, temporarily of new markets. On the other hand, other refiners have not only been called upon to effect a degrading change of yields but also, at the same time, have lost substantial portions of normal markets.

But the industry is petitioning only for sound ad-

justments in order to be able to maintain its proper position in the national economy. This attitude is adopted in full recognition of the enormity of the problems presented to the government agency charged with providing relief. Not least among the factors underlying favorable consideration of the industry's claims for relief is the very great need to keep its refining branch fit for the most efficient production of petroleum products during the emergency. Following closely upon such a consideration is the supplementary one that the industry should be kept financially strong enough to be well prepared for the effects of big obsolescence write-offs growing out of anticipated large scale technical improvements in the immediate postwar period. Certainly these objectives provide good reasons for ceasing to perpetuate ceiling prices predicated upon conditions which have been greatly altered as a result of the impact of the war upon the petroleum industry. Otherwise, it may be said that for the petroleum industry the rules have been changed in the middle of the game and in a manner imposing considerable hardship on the industry.

For another very good reason, the importance of timeliness in providing relief should be recognized. While at the moment it may be beyond categorical proof, there is today a concensus of opinion that a larger volume of petroleum products could be set down in the Atlantic Seaboard area, thus increasing the definite assurance of supplying all essential industry needs and of more nearly satisfying all other desires of consumers without any hurt whatsoever to the most vigorous prosecution of the war, if the units of the industry were freed from the fears of losses, which not only have been threatening but which have been real and substantial. Some of these losses have in effect subsidized other industries. The oil industry ought not to be asked to subsidize other industries and the public generally. Free the industry from these fears by appropriate relief action and the supply of petroleum in the area hurt most by the impact of the war could be increased up to the very limits of the physical capacity of transportation and other appropriate facilities. Parenthetically, it must be clear that no matter what one thinks about the reduction

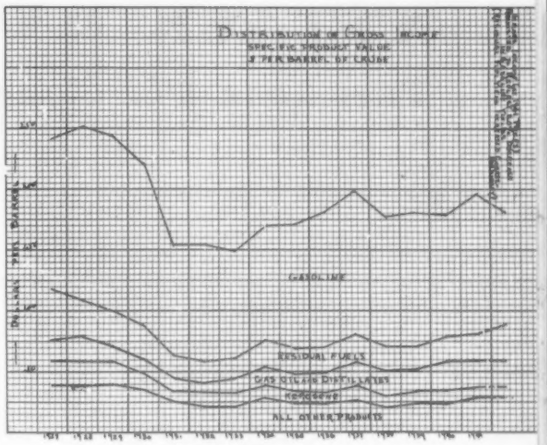


Chart VI

of gasoline usage on account of the need to conserve rubber, there can be no similar explanation for the threat to the comfort and welfare of users of domestic heating oils who have been rationed mildly and who may be rationed rigorously. These needs could be met readily by more high cost transportation and related operations.

Approximate justice is better than no justice at all. The difficulty of providing precise statements of the monetary extent of the hurt incurred by compliance with change of yield orders should be no barrier to the provision of relief through the medium of increases in the prices of products. At best the method of relief by price increase is approximate. Moreover, it is a method which makes it possible for the providing agency to keep control of the situation. Furthermore, there is no necessity for petroleum price increases to have unfavorable effects, either externally, that is, upon the attempts to maintain a satisfactory degree of stability in the nation's price structure, or internally, that is, upon competitive structure of the industry, specifically. In the first instance there need be only due consideration of the fact that the prices of competitive products and services act as anchorages for those of certain products of the oil industry, and that the effect of other price increases of petroleum products is inconsequential with respect to alterations in the general price structure. In the second instance, violence to the competitive structure of the oil industry can be avoided by recognition of the fact that when one important element of the economy is altered arbitrarily, such as industry's price structure, by the adjustment of ceiling prices, then some other element of the economy may have to be altered also. This other element in the matter under consideration may be volumetric control. Volumetric control of production and movement of products is subject to the jurisdiction of another governmental agency and its extensive use might be invoked to prevent serious dislocations among the members of the petroleum industry which might otherwise result from the differential effects of price increases of products not meeting external competition.

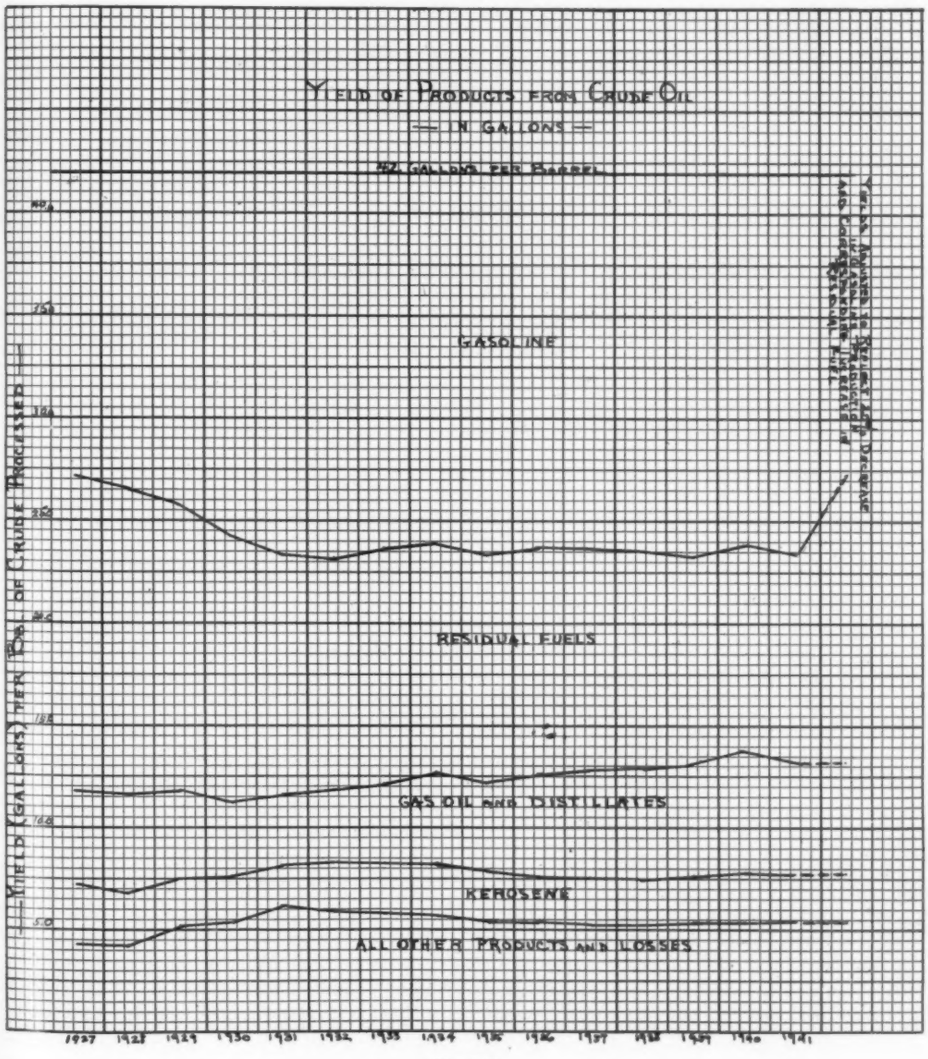


Chart V

ATTACK ON PATENT SYSTEM

Threatens Petroleum Research

Although Protected Processes and Technical Knowledge Have Been Made Fully Available for Furthering War Program Legislative Proposals Would Permanently Abridge Right to Benefit From Discoveries.

By Dr. Benjamin T. Brooks

Dr. E. C. Hughes (left) senior supervisor of experiments at the Standard Oil Company of Ohio's new research laboratory with the model of the long heptane molecule which has been transformed into a ringform to make toluene, one of the primary war products now being furnished.

SHORTLY AFTER the end of World War I the American petroleum industry began a technological renaissance. Methods of finding, production and refining passed through changes calling for vast expenditures. The more important of these new methods and improvements are familiar to all who are well acquainted with this industry. Of course other American industries were improved during the same period and through the same means, scientific research, good engineering and management. That the petroleum industry underwent greater changes during this period than any other great industry, with the possible exception of radio, is indicated by the accompanying data on research personnel quoted by the Temporary National Economic Committee (Monograph 22, page 209).

The building of this research personnel is paralleled by equally expanded engineering staffs and the entire picture includes not only many millions spent on personnel, but also many more millions spent on research and engineering facilities and still much greater sums on applications in the form of field and plant equipment. All this expenditure and technological advance has been made in the confident belief that these investments were reasonably protected by our patent system and the integrity of our courts. Also, as a result of this common belief, most oil companies have pursued very liberal policies as regards the publication of scientific and technical papers. The encouragement of the publication of such scientific and technical advances for the public good, was one of the primary reasons for the establishment of our patent system.

The petroleum industry has an interest in preserving the patent system from destruction or sabotage and while such interest is doubtless shared by other large industries, the oil business has a relatively great interest by virtue of the fact that many of its operations are new enough to be still protected, at least theoretically, by patents; also by virtue of its large stake in research and engineering personnel, well organized for further technological advances. Another matter which should be of real concern is the fact that, although sometimes falsely accused by a few public officials as being obstructionists, the oil industry has pooled its processes and technical information, including in many instances, private research information and pending unissued patents, for furthering our war effort. Patent royalties have been scaled down to the vanishing point or eliminated altogether for the duration. Many of these processes will be industrially important after the war; for example, the manufacture of synthetic rubber. It is indeed a question as to what the status of many processes, disclosed or specially licensed to aid in the war, will be after hostilities cease. Will the "emergency" arbitrarily be declared to continue, and indefinitely? More concretely, however, the patent system is under attack, not as to details or minor matters of procedure, but fundamentally. It is clear from the voluminous socialistic literature that patents, giving the inventor or his assignees a temporary monopoly of his invention, have no place what-

ever in either the socialistic or communistic scheme of things. Much of the propaganda and legislative attack now being directed against the patent system stems consciously or unconsciously, from this collectivist point of view.

The Constitution, with characteristic brevity, states that to the Congress is delegated the power to promote the progress of science and the useful arts "by securing for limited times to Authors and Inventors the exclusive right to their writings and discoveries." However, it is not necessary to amend the Constitution to nullify our patent system. All that is necessary is for the Supreme Court to re-define invention in terms that will invalidate most of our existing patents. The present attitude of this court to patents is well known and is shown by its recent record in sustaining only one out of sixteen patents in cases before that court. In one recent case the majority opinion declared a patent to be invalid unless it showed a "flash of genius." This of course is no definition, but under such a precedent probably 98 percent of all existing patents could be invalidated. Such a criterion could invalidate practically all patents which are the result of painstaking systematic research, particularly those inventions resulting from the effort of a group of investigators as is so often the case in organized industrial research. If Midgley and Boyd had not tested many hundreds of compounds for their anti-knock value in gasoline, but had pounced at once upon tetra-ethyl lead through some mysterious stroke of inspiration they might have been credited with a "flash of genius," or can there be co-inventors? If Burton could have jumped at once from his pressure shell still of 1912 to the combination tube cracking still of 1934 he too could be credited with a flash of genius. The flash of genius decision is too recent to determine whether other courts will follow the Supreme Court in this view or whether in future cases this court will clarify for us what is meant by a flash of genius. A member of the Temporary National Economic Committee recently wrote, "The Constitutional provision is as the statute makes it; and the statute has whatever meaning the stream of administrative and judical rulings give to it." (Monograph 31, page 2).

Pending legislation in the Congress not only reflects the judicial antipathy toward patents, but emphasizes public interest versus private interest.

Growth of Research Personnel from 1927 to 1938 by Industrial Group:

	Percentage Increase
Petroleum and its products	538.7
Food and kindred products	255.1
Textiles	252.9
Motor vehicles	190.2
Iron and steel	189.4
Paper and Allied products	177.5
Chemicals	175.5
Glass and ceramic products	166.4
Rubber products	101.8
Non-ferrous metals	72.7
Electrical machinery, apparatus and supplies	58.1

Again, the TNEC writers state: "The problem demands a series of attacks upon a number of levels . . . The rank growth of custom by which sanctions are held in bondage to vested interests, needs to be trimmed away or subdued to the public interest." And again, "As yet the line between the patent privilege and the general law is not clearly defined. The patentee insists that 'exclusive' is an absolute right; the government retorts that all rights are subject to the general law and that letters patent create no immunity to antitrust. A large body of industrial practice is in accord with the claim of the patentee; the trend of judicial decision seems to favor the government's decision." In connection with the latter statement, the Commission refers to the decision in the case of Ethyl Gasoline Corporation vs. the U. S. 309 U. S. 436 (1940).

Electron diffraction camera used in Shell Development Company's laboratories for the study of catalysts which have become the most important instrument of war time refining.

Among the practices of which the TNEC complain in their report to the Senate was that of cross-licensing and pooling of patents, and in this connection they refer to the cross-licensing of cracking patents which was tried in U. S. vs. Standard Oil Company of Indiana (283 U. S. 163) (1931). In this case the court found that "no monopoly or restriction of competition in the business of licensing cracking patented processes resulted from the execution of these agreements" and the court refused to sanction or to condemn the practice of cross-license. The Commission admits that any company having made an important contribution as expressed in one or more patents having to do with the general subject of a patent pool, thereby becomes a member of such a pool. As the court found in this cracking patent pool, it can be equally well said that the cross-licensing of patents relating to polymerization has likewise not interferred with the widespread general adoption of polymerization processes. Processes in patents relating to polymerization were contributed by Standard Oil Company of Indiana, Texas Company, Gasoline Products Company, M. W. Kellogg Company, Standard Oil Development Company and Phillips Petroleum Company. In the same way the development of alkylation was shared by Shell Development, Standard Development, Texas Company, Anglo-Iranian and Universal Oil Products Company. The small royalty proposed was approved by the government and the process has been widely licensed and installed. Without these processes it would have been impossible to produce the vast quantities of 100-octane gasoline now required by the United Nations. As in the case of the oil cracking patents, if any one company had held out for unreasonable royalties, the full advantage of incorporating all features contributed by the various patents concerned could not have been obtained.

If the demand for royalties appears to be too high to permit general adoption this inevitably stimulates others to develop independent competing processes. This may be the explanation of the fact that chemists of the Standard Oil Company (New Jersey) developed a catalytic cracking process known as the "fluid catalyst process" now being widely installed and which can be operated to produce large yields of butene required for the manufacture of butadiene and synthetic rubber. Our socialist friends appear to see in these cross-licensing agreements an expanded monopoly. They fail to understand, or do not mention, the great complexity of such operations and the improvements and details of apparatus in which such processes are carried out, the pooling of which makes for most efficient operation. To prevent such cross-licensing would seem to be an-

Research on the effects of sulphur on antiknock quality of fuels. Ethyl Corporation, in whose laboratories this picture was taken, has spent years studying motor fuels under varying conditions; these studies are now proving of decisive importance in the world wide struggle for aerial supremacy; the patents, however, did not result from "a flash of genius."

alogous to forbidding the various members of an orchestra playing together. The real bone which sticks in the throat of these critics, however, is that the pool may collect a royalty from others who have made no contribution to the development. As the TNEC writers say, "The instrument of the progress of science had become a weapon for the pursuit of gain." Presumably, the orchestra if permitted to play together should not defray their expenses or enjoy any financial return from the gate receipts.

Under the guise of war-time emergency, two bills have been introduced in the Senate and the Senate Patent Committee has recently been conducting so-called hearings in regard to these bills, S. 2303 and S. 2491. The Congress has been flirting with the idea of compulsory license of patents for several years. The Bill S. 2303 would permit the President during any war involving the United States to find and declare that the manufacture, use or sale of any article or process is insufficient and should be expanded whether for government or not. This act would then come into force automatically and any person could then apply for a license under the patents upon terms prescribed by the President. There is no provision whatever for the patent owner to be heard and show what is a reasonable royalty or that there is sufficient manufacturing capacity in the country, so that there is no need of expanding the manufacture by others. The owner of the patent will be unable to obtain an injunction to stop such use by others whether licensed or not. This bill is definitely not limited to the war period, since the President on the advice of anybody may seize the patents, application, invention or license not only when the United States is at war, but as the Assistant Attorney General has pointed out, using the words of the bill: "during any period of national emergency declared by him to exist." We have had a series of some forty odd national emergencies since 1932. The President may thus act without a hearing and the first inkling of it that the patent owner would get would be a notice from the Commissioner of Patents. Furthermore, failure to pay royalty or judgments will not invalidate the license or permit stopping the defaulter from infringing. There is no provision for terminating the license or returning the patents to the original owners after the emergency has passed.

We already have a general statute giving the government full power to have any patented product made or process used for the government by any manufacturer without interference by the patentee and any compensation due the patentee is to be settled in the Court of Claims. However, the proposed Bill S. 2303 is not confined to production for the government, but throws the patent wide open for use by anyone for the purpose on the decision of a subordinate official delegated by the President and without a hearing. Under this act, any industry or any particular company could be punished by a hostile administration or unfriendly advisor of the administration. Apparently, under this act, all the patents relating to synthetic rubber for example may be licensed to

anybody for as long a time as the President may choose to consider an emergency to exist and upon such terms as he or his favorite advisors may choose.

Senate Bill 2491 is not war-time or emergency legislation, but is intended to be permanent. It goes a long way in curtailing the rights of patentees and thereby rendering the patents themselves of doubtful value. According to this bill, the use of a patent may be thrown open to the public if the patentee has failed either to use it commercially within three years after issuance or to license it to others within that period. Furthermore, if at any time the patentee has refused to issue licenses under the patent for any reason whatsoever, the penalties of the act may be invoked. If a patentee doing business only in the Eastern States were to license another manufacturer to operate only on the Pacific Coast, the penalties of the act may be invoked. If the patentee licenses another to the use of the invention and limits his use to the product or process of the other, the penalties of the act may be invoked and the patent declared void.

It is provided that in hearings held by the Commissioner of Patents under this act, the Commissioner is not bound by the rules of evidence. Testimony, not under oath, and hearsay, whether true or not, opinions sound or not, in fact, practically anything will be received and heard and

Shell Development's machine for testing relative resistance of lubricating oils to oxidation. These and similar studies have placed the United States oil industry in a position to furnish quantities of aviation fuels and lubricants of a quality superior to those of any other nation. Without the protection of the patent structure such privately financed research would have proved impractical.

the truth or falsity of such evidence may never be determined. One section of the bill may perhaps be interpreted to bar completely transfer of a patent from an inventor to a corporation.

The petroleum industry has been throughout its field largely American and by far the great majority of processes now used have been American inventions. However, one of the major changes currently taking place revolves around the use of petroleum products, cracked gases and the like in the manufacture of chemicals, solvents, synthetic rubber, toluene and so forth. Certain companies have been publicly castigated for having acquired American rights under inventions developed abroad. The Anglo-Iranian Oil Company participated in the development of alkylation for making high octane aviation gasoline. This company was included in the cross-licensing agreement with American companies as noted above. The case of the synthetic rubber patents acquired by the Standard Oil Company (New Jersey) from the I. G. Farbenindustrie, the acquisition of patents for manufacture of hydrogen by the New Jersey Company and the acquisition of the Carballoy patents by the General Electric Company, have been condemned in general terms by public officials and these companies have been charged with impeding or frustration of our war effort as regards American use of these processes or products. By acquiring American rights under these patents, and, in some cases also rights in certain foreign countries, these companies have been accused of entering into a so-called "Cartel" arrangement with all sorts of horrible corollaries.

In the case of hydrogen, the Standard Oil Company (New Jersey) wanted the rights for the hydrogenation of oil and was not concerned with the use of hydrogen for use of synthetic ammonia. The charge has been made that by acquiring a restricted right, the company gave the German interests the ammonia rights. The German interests had the ammonia interests all the time; Jersey simply did not acquire them. They certainly would have been criticized with equal severity if they had acquired them. This whole matter has been fogged by many ill-considered accusations and Mr. Thurman Arnold has suggested as one possible remedy that the U. S. Government carry on sufficient research so that American industry would be entirely independent of processes developed abroad. This seems a rather large order, as we have a monopoly neither of brains nor effort. Important technical contributions and discoveries have come from all nations. As to the synthetic rubber, more particularly the now well-known Buna N and Buna S types, if the Standard Oil Company (New Jersey) had not acquired the American rights from the German I.G. and these rights had remained in German control, no American company could have undertaken to manufacture these products prior to December 1941 without incurring the heavy penalties or infringements of the I.G. patents. Apparently, this hue and cry, implying impropriety, disloyalty or worse, is new in the entire history of international relations as regards patentable inventions.

The desirability of acquiring foreign skills and inventions as a matter of national policy goes back to days long before issuance of letters patent became a well defined institution. In 1331 a weaver from the low countries emigrated to England and was promised the King's protection in return for teaching his art to Englishmen. A similar grant of privilege was extended to some clock-makers from Delft. During the time of Queen Elizabeth, Francis Bacon stated, "If any man out of his own wit, industry or endeavor find out anything beneficial for the commonwealth or bring any new invention which every subject of this realm may use; yet in regard to his pains, travail and charge therein Her Majesty is pleased to grant him a privilege to use the same only by himself for his deputies for a certain time." This is one kind of monopoly.

George Washington particularly favored the introduction of inventions from abroad, stating in 1790: "I cannot forbear intimating to you the expediency of giving effectual encouragement, as well to the introduction of new and useful inventions from abroad, as to the extensions of skill and genius in producing them at home." In none of our patent statutes is it suggested that the right to acquire letters patent be limited to American nationals. We have similar rights in other countries under the International Patent Convention. Our manufacture of high octane aviation gasoline was assisted by the research of the Anglo-Iranian Company. Our manufacture of synthetic rubber has been vastly aided and expedited by the acquisition by the Standard Oil Company (New Jersey) of American patent rights and much research information simultaneously acquired long prior to the war from the German I.G. Similarly, the manufacture of toluene from petroleum which is necessary for the manufacture of TNT in the large quantities required by modern warfare was greatly aided by the acquisition of the American rights under certain other German I.G. patents which were acquired by the Standard Oil Company (New Jersey).

The present attack upon our patent system seems to center around the idea of the limited temporary monopoly granted by the Constitution as an encouragement to invention; also running through all of the various hearings and legislative proposals is the castigation of the profit motive. If those industries, such as the petroleum industry, which have a stake in the preservation of these rights and encouragement to technical advance do not successfully meet the challenge of these socialistic and communistic ideas, all technological progress will be retarded, the publication of scientific and technical matters will shrivel up to a residue of academic theses, research will be driven under cover and the companies which will suffer most in this Utopian scheme of things will be the small companies who cannot afford research, particularly since any discoveries they do make can be taken over with impunity by more powerful competitors.

RESEARCH Has

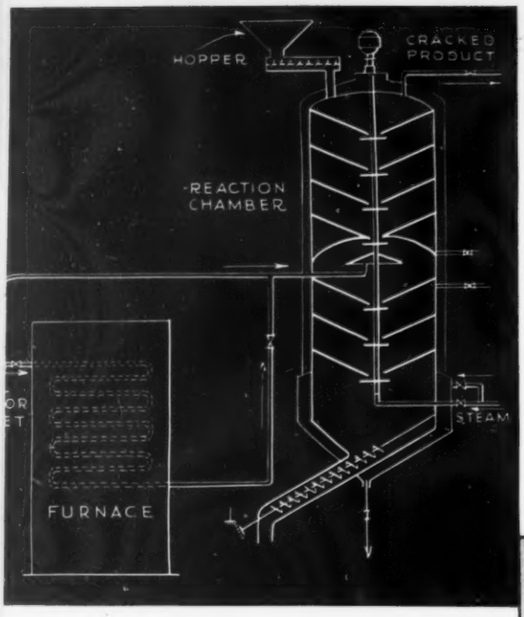
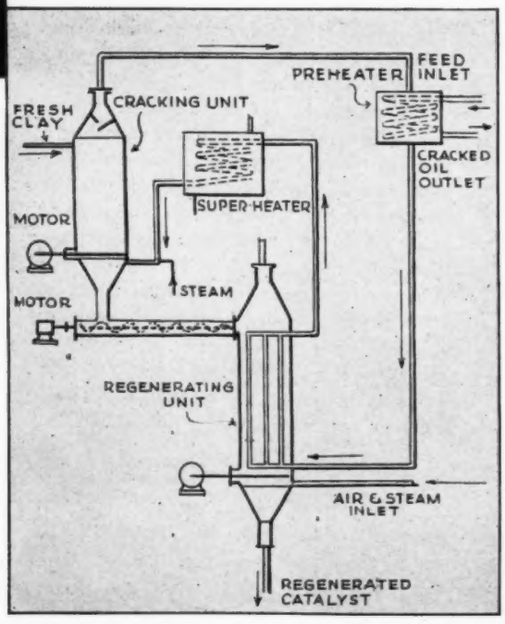


Figure 1: granular catalyst from hopper feeds into tower equipped with baffle plates dropping onto discs that are spun by motor at top of tower giving intimate contact with vapors from furnace.

Figure 2: catalyst feeds into reaction chamber from inlet marked "fresh clay": after reaction, catalyst is fed to regenerator by conveyor: rate of catalyst feed to conveyor is controlled by vibrating screen at bottom of reaction chamber.



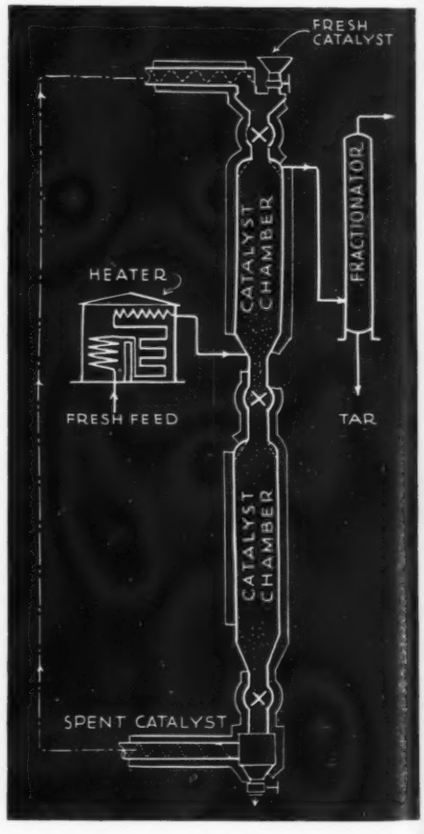
THE MODERN HISTORY of the petroleum refining industry is marked by two outstanding technical developments. First was the introduction of thermal cracking, and the other was the development of catalytic cracking, represented by the Houdry process, which was quickly followed by other methods of applying the catalytic principle. In one form or another the catalytic principle is being employed throughout the world.

The popularity of catalytic cracking in comparison with thermal cracking lies not only in its greater ability to turn out larger yields of higher grade products from the same amounts of raw material, but also in its versatility. By employing catalysts in his cracking operations the refiner may control the course of the reaction, and turn it into directions that are hardly (if at all) possible in thermal cracking. By choosing his catalysts and his operating conditions the refiner is able to subject his material to desirable processes of reforming, hydrogenation, dehydrogenation, polymerization, depolymerization, isomerization, cyclization, alkylation and so forth. It is not too much to say that the science of catalysis has made it possible to convert any known type of hydrocarbon into any other known type. This great versatility makes of crude petroleum a source from which an enormous list of useful substances may be derived, some of which have become of crucial importance in this time of national danger, such as 100-plus octane number gasoline, artificial rubber, toluene, alcohol.

In its mechanical aspects the catalysis of petroleum has taken two forms, which have to do with the physical manipulation of the catalyst. In the original form, represented by the Houdry process, for example, the catalyst, in the shape of pellets or granules, is arranged as a fixed layer in a container so that a stream of oil vapors may be blown through. By contact with the grains of catalyst the oil is cracked or otherwise transformed in desired manner. After a certain lapse of time the catalyst loses its activity, so that it becomes necessary to interrupt the operation and give the catalyst a regenerative treatment, whereupon the cracking process may be resumed. In this form the process is periodic, or discontinuous. During the time required to regenerate the catalyst the cracking plant is virtually shut down, although, by having two or more catalyst cases, one may be in operation while another is being regenerated; thus a continuous stream of cracked products may be kept going through the refinery processes.

In the form given to it by Houdry and his associates the intermittently operated, fixed-bed type of catalytic cracking has had and is still having distinguished success. However, within a very short time after the appearance of this process petroleum technologists all over the world were busy with the idea of substituting the fixed bed of catalyst with a movable or moving bed. In this conception of the matter both the catalyst

Figure 3: Upper chamber is catalyst chamber and lower chamber is regenerating vessel (not "catalyst chamber" as marked). In this system the rate of flow of the catalyst is controlled by three star valves indicated by X.



Produced Variety of Catalytic Cracking Methods

Examination of Patent Claims Reveals Numerous Applications of Processes Employing Moving Bodies While Fixed Bed Method Continues in Extensive Operation

and the oil vapors would be in motion through the catalyst case; the time of their passage through the case would be just long enough for the catalyst to exert its maximum cracking effect. On issuing from the case the cracked vapors would pass to the fractionating equipment and the exhausted catalyst would pass to a separate vessel, where it would be regenerated and returned to the process. The cracking operation would then become continuous instead of intermittent as shown in accompanying illustrations.

Numerous inventors have taken out patents on the principle of moving the catalyst through the zone where cracking is going on. These patents generally begin with a preamble that reviews the prior art, and states a variety of reasons why a moving catalyst should be preferred over a fixed catalyst bed. As a first reason they cite the fact that because operations with a fixed catalyst bed are intermittent, it is necessary to provide two and in some cases three catalyst cases in order to have continuous production; this requires a relatively high investment cost. Where the oil vapors are blown through a fixed bed the catalyst must be in the form of relatively coarse granules in order to allow free passage of the vapors; since catalytic activity is a surface action, and as large granules have a smaller surface than the same weight of small granules, the catalyst case must be built correspondingly larger. It is also alleged that in a fixed bed channeling is bound to occur, so that the amount of active catalyst surface is reduced. Again, it is pointed out that the use of a fixed mass of catalyst does not admit of easy control of the ratio of catalyst to vapor or gases other than by varying the velocity of the vapor or gas, and even this ratio is said to be only approximate on account of channeling. A further point is made of the fact that when the activity of a fixed catalyst bed has become exhausted it has to be regenerated without removing it from the case. Now, the optimum temperature for cracking is considerably lower than the temperature that prevails during the regenerating operation. And as cracking and regeneration follow in quick succession, elaborate means are required for controlling these shifts of temperature; even so, the structural elements of the case are exposed to severe strains. It is not denied that fixed catalyst beds do a satisfactory job, and the foregoing objections to the system amount to a complaint that this type of operation requires large and well built equipment, which is expensive. In addition it is pointed out that the product of a fixed catalyst bed is not of uniform quality. When a freshly regenerated case is put back on stream the first vapors may contain 50 percent or more of gasoline, while at the end of the cycle the proportion may drop to 15 or 20 percent. In continuous catalysis the supply of fresh catalyst is constantly renewed and the cracked product is said to have a fairly constant composition. Also, in the continuous process the production of cracked product per unit of time can be increased by increasing the circulation rate of the catalyst. This ability to pass large quantities of catalyst through the reaction zone opens the possibility of employing what may be called cheap, low grade catalyst material, that might be used once and thrown away, thus eliminating the bother and expense of regenerators. However, it does not yet appear that any patentee has definitely reached this Ultima Thule of economical operation; reliance is still placed in regeneration.

For their part, the advocates of the fixed catalyst bed have not been behind hand with arguments in support of their system. It is pointed out that the moving catalyst is so subject to attrition and mechanical loss that only the cheapest clay catalyst can be used, and these cheap catalysts cannot produce the same quality of product that is turned out by synthetic catalysts that are spe-

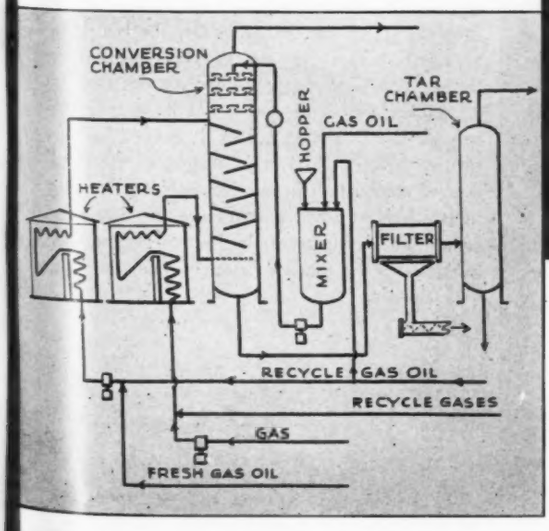


Figure 4: Powered catalyst is mixed with oil in mixer to form slurry which flows from top of conversion chamber counter current to vapor feed; catalyst is subsequently removed by filter.

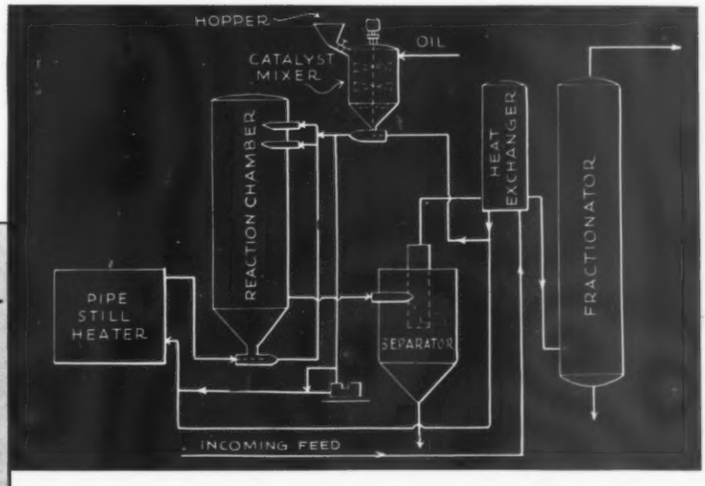


Figure 5: the slurry formed by mixture of oil and catalyst is picked up by vapor at bottom of mixer and blown into reaction chamber. Catalyst is separated, reacted vapors going to fractionator via heat exchanger.

cifically designed for attaining the best results. The inventors of processes for the use of moving catalysts have followed two principal lines. Along one of these lines they use a definitely granular catalyst material, which may be around 8 mesh or 50 mesh. Along another line they use a finely powdered catalyst which may be of the order of 200 mesh or finer. Again, the processes that use finely powdered catalysts fall into two categories. In one of these the catalyst is mixed directly into the stream of liquid oil on its way to the heating furnace that is to raise the mixture to the cracking temperature. In the other the oil is first vaporized, and the powdered catalyst is injected into the stream of vapor with the aid of a blast of some sort of gas. In either case, and whether or not the powdered catalyst is injected into liquid oil or into oil vapors, the resulting mixture is subject to the physical laws of fluid flow, and can be pumped through pipes and other vessels as though it were a fluid. A catalyst that can be thus treated is sometimes referred to as a "fluid catalyst," which is rather a loose way of putting it, because no matter how finely they are powdered the cracking catalysts still retain their nature as solid materials.

In examining patent literature it is well to bear in mind that the patentee, or his patent lawyer, is generally careful to disclose no more than will be necessary to establish claim to the principle of the invention. Operating details are often purposely confused, or concealed, with the idea of placing difficulties in the way of possible infringers. While the law requires that the essentials of the invention be disclosed, the drawings that illustrate the process are often so crude as to be practically unusuable without an intimate knowledge of particulars that the inventor keeps to himself. However, the principle must be there. The three types of moving catalyst processes herein briefly described were patented in the United States and European countries a considerable time before the entry of this country into World War II. As stated, these inventions are here described to illustrate generally known principles only. Many of the important details are of necessity omitted from this article.

In the design illustrated in Fig. 1, the granular catalyst is fed from a hopper by a screw conveyor to a reaction chamber which is furnished with a system of interior baffles, each of which directs the falling stream of granules to a whirling plate that is attached to a motor-driven vertical shaft. In falling through the reaction chamber the granules are met by a rising current of vaporized oil. The catalytically cracked product passes out at the top; the granules of catalyst, which will have exhausted its cracking ability by the time it reaches the bottom of the case, are withdrawn by a screw conveyor for regeneration and reuse. In the lower part of the chamber provision is made for injecting steam for the purpose of freeing the catalyst granules from adhering oil.

Fig. 2, represents a scheme for employing a downflowing granular catalyst in a reaction chamber without interior baffles. Near the bottom of the cracking unit is a vibrating screen through which the catalyst passes at a rate that can be regulated. After passing the screen the catalyst is withdrawn by a screw conveyor and transferred to a regenerating chamber. As shown in the drawing, reproduced on page 52, the heat of regeneration is used to preheat the incoming feed.

Fig. 3, represents an outfit for employing a downflowing granular catalyst wherein the reaction chamber is placed above the regenerating chamber, so that the flow of the catalyst is continuous through both. Fresh catalyst is introduced through a hopper at the top of the reaction chamber, where it is mixed with regenerated catalyst that is arriving by way of a screw conveyor. The combined charge of fresh and regenerated catalyst is admitted into the reaction chamber through a rotating star valve. A similar rotating star valve passes the catalyst from the bottom of the reaction chamber into the regenerating chamber, and a third star valve allows the regenerated catalyst to pass into a screw conveyor for return to the top of the reaction chamber. The three star valves are synchronized to act in unison so that the rate of passage of the catalyst can be regulated at any desired rate.

Fig. 4 shows a scheme for using powdered catalyst by mixing it with a portion of the liquid petroleum product which is to be catalyzed. The catalyst is fed through a hopper into a mixer, where it is stirred up to make a slurry with fresh or recycle gas oil. The slurry is pumped to the top of the reaction chamber, which is outfitted internally somewhat like a baffled fractionating column. As the slurry descends through the conversion chamber it first meets the rising vapors of a recycle gas oil and then a stream of hot recycle gas. The slurry of reaction products and catalyst now passes to a filter, where the spent catalyst is removed, and the cracked oil product enters a tar separator on its way to the fractionating system for final treatment.

Fig. 5 represents a catalytic reforming process which employs the principle of making a slurry of the catalyst and a part of the liquid feed. These two are incorporated together in a mixer. The main portion of the feed is preheated and the vapors, under a considerable pressure, are used to eject the slurry from the bottom of the mixer into the upper part of the reaction chamber. From near the bottom of the reaction chamber the product is blown into a separator, where the spent catalyst is removed and the liquid products pass on through a heat exchanger to the fractionating system. As indicated in the drawing, arrangements are made for passing a portion of the unmixed feed through a pipe still which is used for recirculating the slurry through the reaction chamber. (See diagram on page 53).

The scheme illustrated in Fig. 6 also employs the principle of making a slurry of the catalyst with the product to be cracked or reformed. The vaporized feed is introduced into a fractionator, where the gas oil and naphtha fractions are removed. The heavier distillate fraction goes to a mixer, where it is incorporated with the powdered catalyst; after preheating to vaporize the oil, the mixture is forced through the reaction chamber, which consists of an externally heated coil. The reaction products, in vapor form, are blown into a cyclone separator, where the solid catalyst is removed and the vapors enter the lower part of the fractionating column. The bottoms from the fractionator are heated and soaked to remove the last traces of volatile products, which are inducted into the cyclone separator. The spent catalyst is regenerated.

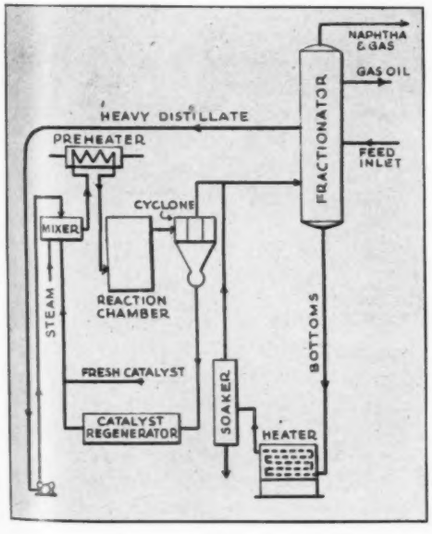
The scheme shown in Fig. 7 is based on the so-called fluid catalyst principle. The finely powdered dry catalyst is delivered from a catalyst hopper to a line through which gas from the fractionating column is being blown into the catalyst reaction chamber. Within this chamber, the upturned end of this pipe abuts the downturned end of a pipe through which the vaporized feed is forced into the reaction chamber. The two gaseous streams thus impinge on one another and become thoroughly mixed, and together with the catalyst, in dust form, pass out of the bottom of the reaction chamber into a condenser. Here part of the liquid products condense, and the mixture of vapor liquid and solid passes into a separator. Here the vapors pass directly to the fractionator, the liquid and solid are separated by filtration, and the spent catalyst is steamed and regenerated for further use.

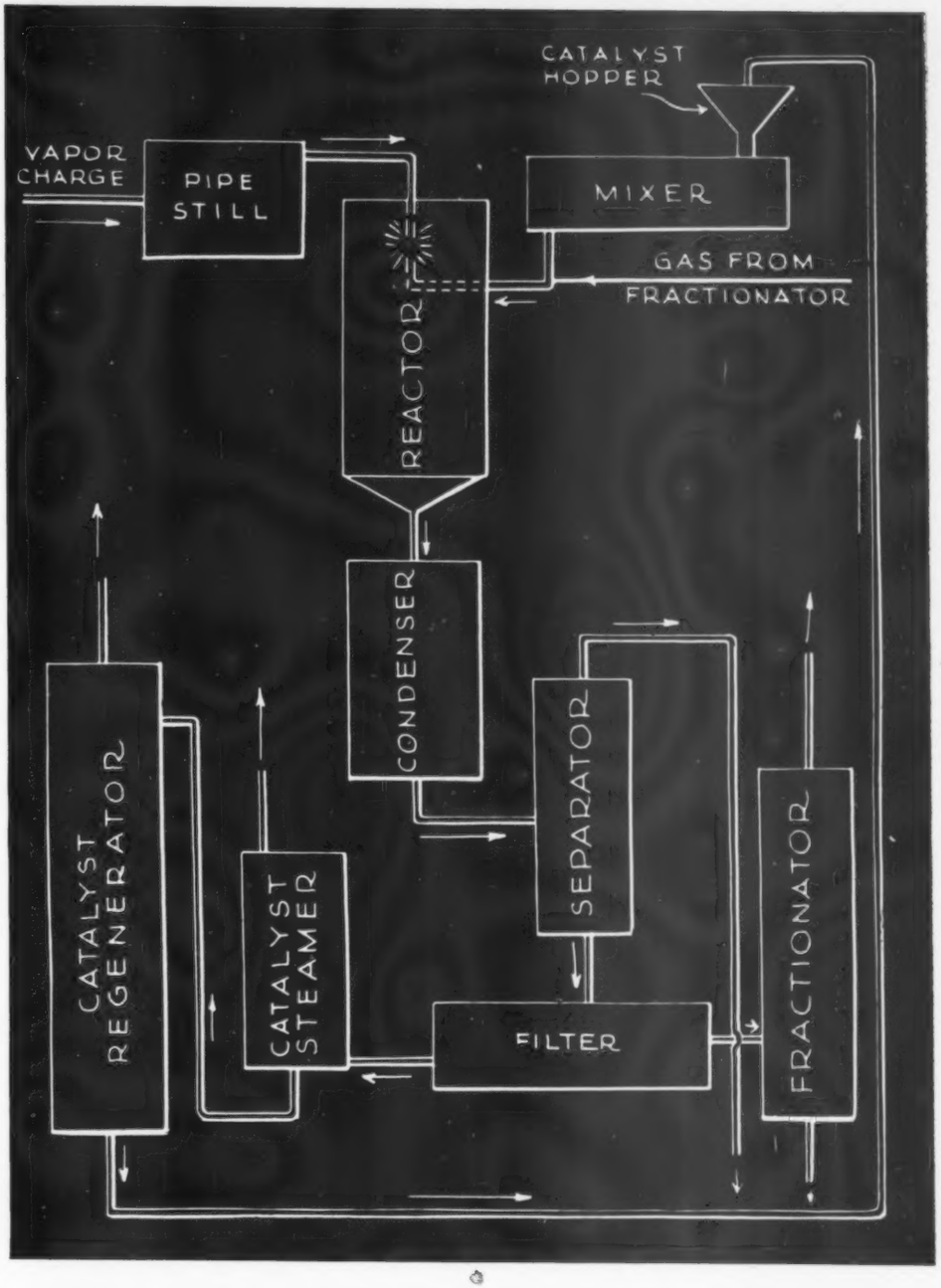
Fig. 8 represents another form of a fluid catalyst process in which the petroleum feed and the hydrocarbon reaction products are gaseous throughout the operation. The vaporized charge is blown into the reaction chamber, which takes the form of a long tube. In the fore part of this tube the stream of vapor picks up a charge of fresh and regenerated powdered catalyst. The two travel together to the end of the reaction tube, which they reach by the time the catalytic reaction is finished. Then the gaseous reaction product and the catalyst dust enter a cyclone; the vapors pass on to the fractionator and the dust falls through a purging chamber, where adhering vapors are blown out by a current of steam or gas. The spent catalyst then enters a long regenerating tube similar to the reaction tube, the two being arranged so that they can exchange heat. Here the spent catalyst powder comes into contact with air admitted through a series of ducts; the carbon on the catalyst particles is burned off and the regenerated catalyst is purged of the products of combustion in another purging chamber, to which is attached another cyclone dust separator. The intensity of the heat of regeneration is regulated by the admission of flue gas along with the air.

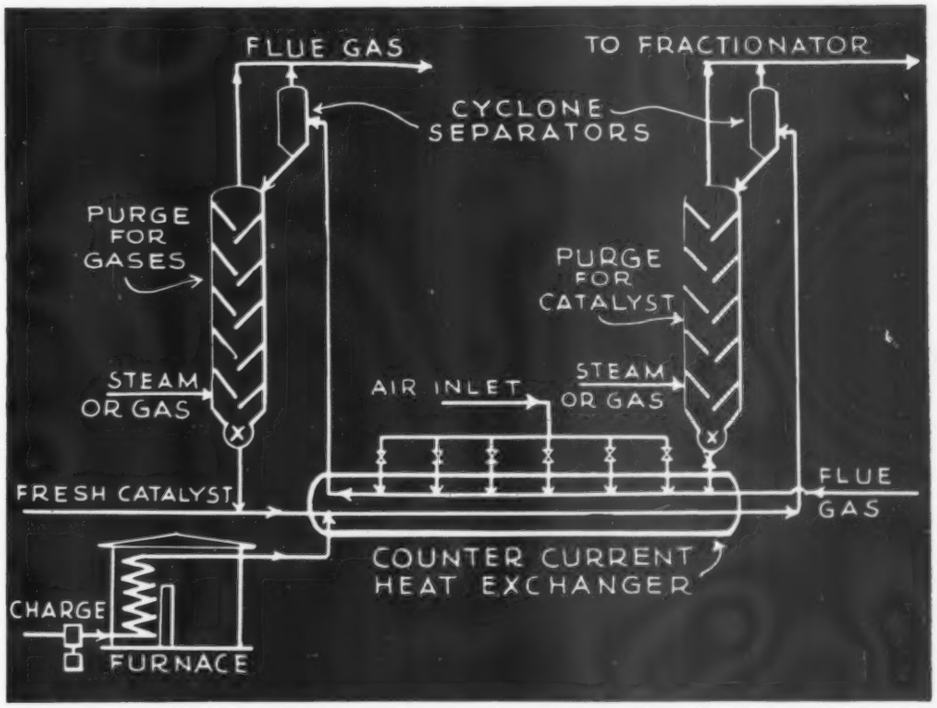
Right, ***Figure 7:*** *finely powdered catalyst is picked up by gas at bottom of catalyst mixer, fed into reaction chamber, thence to condenser to be liquefied and fed into separator; from separator reacted vapors go to fractionator and catalyst goes to filter.*

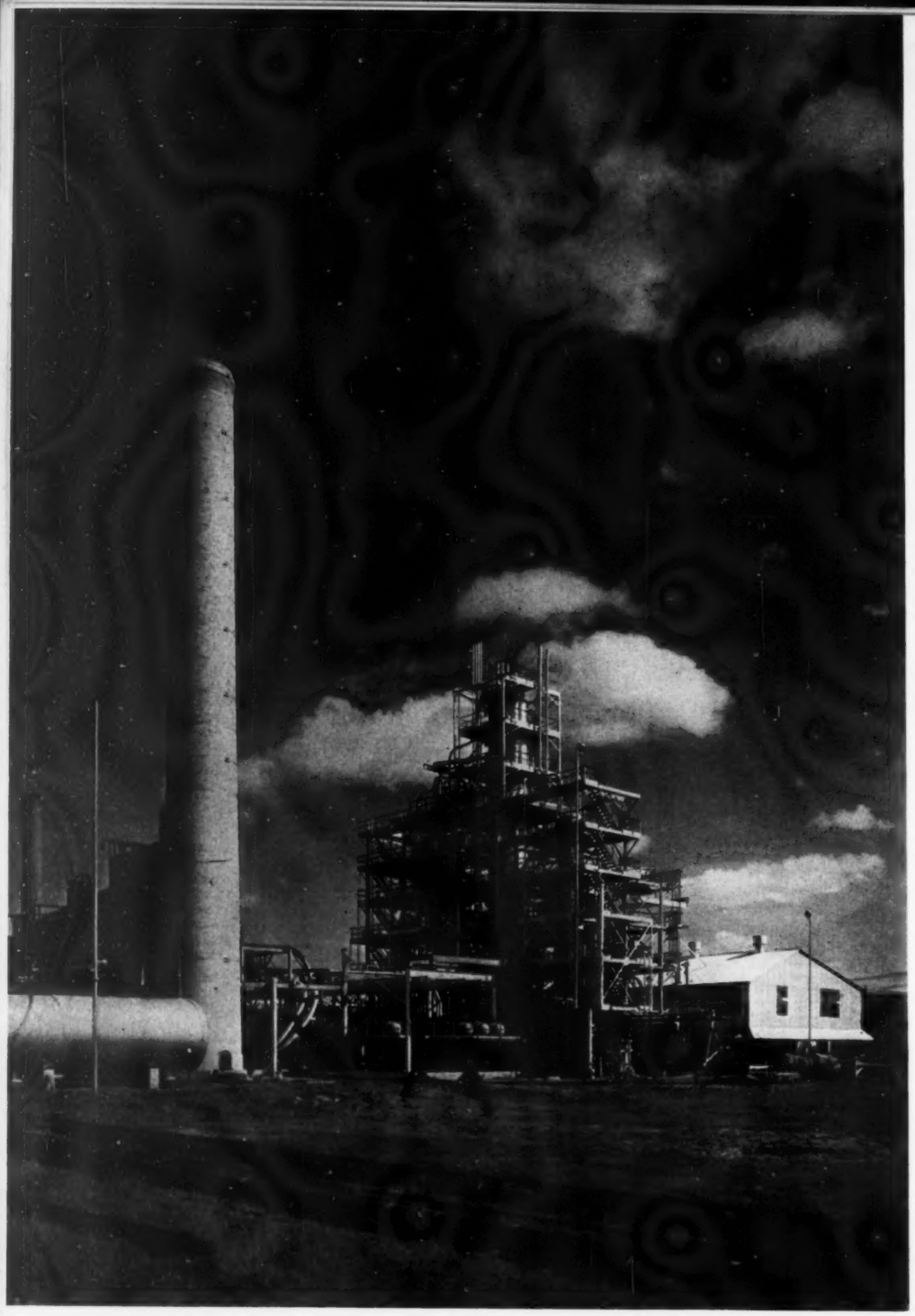
Below right, ***Figure 8:*** *charge from furnace feeds through reaction chamber (marked "counter current heat exchanger") having picked up finely divided catalyst at entrance to chamber; vapors are taken off to fractionator while catalyst passes through purging vessel to regenerating chamber. Regeneration of catalyst and reaction of catalyst and charge occurs in same vessel which serves also as a heat exchanger.*

Directly below, ***Figure 6:*** *slurry of catalyst and oil is formed in mixing chamber and fed to reaction chamber: reacted vapors pass from cyclone separator to fractionator while catalyst, having been removed by centrifugal force in cyclone, is fed to regenerator.*









A modern refinery under construction just before the war; current events have forced this type of plant to modify its technique for lower production of motor fuel in favor of greatly increased yields of war products from refinery gases that formerly found little commercial demand. Photo by Robert Yarnall Richie.

REFINERY TECHNOLOGY

In War – And After

By Dr. O. W. Willcox

IT IS PERHAPS unnecessary to begin this article by remarking that the technology of oil refining has been profoundly affected by economic disturbances arising out of war conditions. It is also more or less self evident that the technological revolution which is being born from the present national need will have a lasting effect on the industrial and economic structure of the refining industry, which is right now striking deep roots for a new destiny.

Before the Hitlerian eruption the American oil industry existed primarily to supply gasoline to the 28 million or more automobiles and the 6 million trucks of the United States. At least 52 percent of all crude oil was being converted to motor fuel; some of the remainder went into the production of lubricants, and the rest was marketed as minor though more or less profitable by-products—napthas, gas oils and bunker fuel. The refineries and natural gasoline plants made what use they could of the light products—butane and propane—and what they could not use commercially they burned along with their waste gases. The advent of the war disrupted this normal adjustment of the refining industry to its market. One of the most drastic shakeups was the one that was forced by the curtailment of motor gasoline consumption due to interruption of tanker transport to the eastern refineries, and to inadequate rail transportation from the southern and mid-continent refineries. Added to this reason for a decrease in motor gasoline consumption was a more or less pronounced disposition of motorists to curtail their driving in order to conserve tires. For these reasons alone, if the refiners maintained their throughput they would have had to revise their technology in order to produce less gasoline and more of other products. Drastic revision of refinery technology also became necessary for other reasons. Military exigencies created unprecedented new demands. Enormous quantities of aviation gasoline were required, and this demand made it necessary to create whole new technologies. The military machine also looked to the oil refining industry for a huge supply of toluene for explosives, a demand which again required a new technology. Then the complete extinction of the supply of natural rubber that used to come from eastern plantations created an insistent demand for a supply of synthetic rubber, and to meet that demand the refining industry had to create still another new technology to supply the raw material.

Fortunately, the petroleum industry had already laid the foundation on which these new technologies could be quickly established. More than any other industry in the United States, the oil refinery industry had accumulated a vast backlog of fundamental research, much of which merely awaited a suitable conjunction of circumstances to become of practical use. Through the years the properties and natures of hundreds of the individual hydrocarbons contained in crude oil and natural gas had become known in great detail, and on the basis of this knowledge the oil

laboratorians had developed model processes for combining these parent substances among themselves, and with other materials to produce a nearly infinite variety of raw materials and finished products. The level to which petroleum research had been raised is well indicated in the statement that the petroleum chemist is able to convert any known type of hydrocarbon into any other known type. These conversions naturally required the development of new techniques for effecting them, first in the laboratory and then in the pilot plant. Out of these studies there grew a great body of information that has been incorporated in many thousands of patents.

Through their acquisition of fundamental knowledge of the mechanisms of hydrocarbon chemistry, the refinery technologists were prepared to undertake any job of hydrocarbon rearrangement, including the splitting of large molecules into small ones, the joining of smaller molecules into large ones; to dehydrogenate paraffins to olefine; to rehydrogenate olefine to paraffins; to convert straight hydrocarbon molecules into branched hydrocarbons, or to tie them in rings; and to alter operating conditions so as to produce more of one kind of petroleum product and less of another, depending on the state of the market or on whatever emergency might arise.

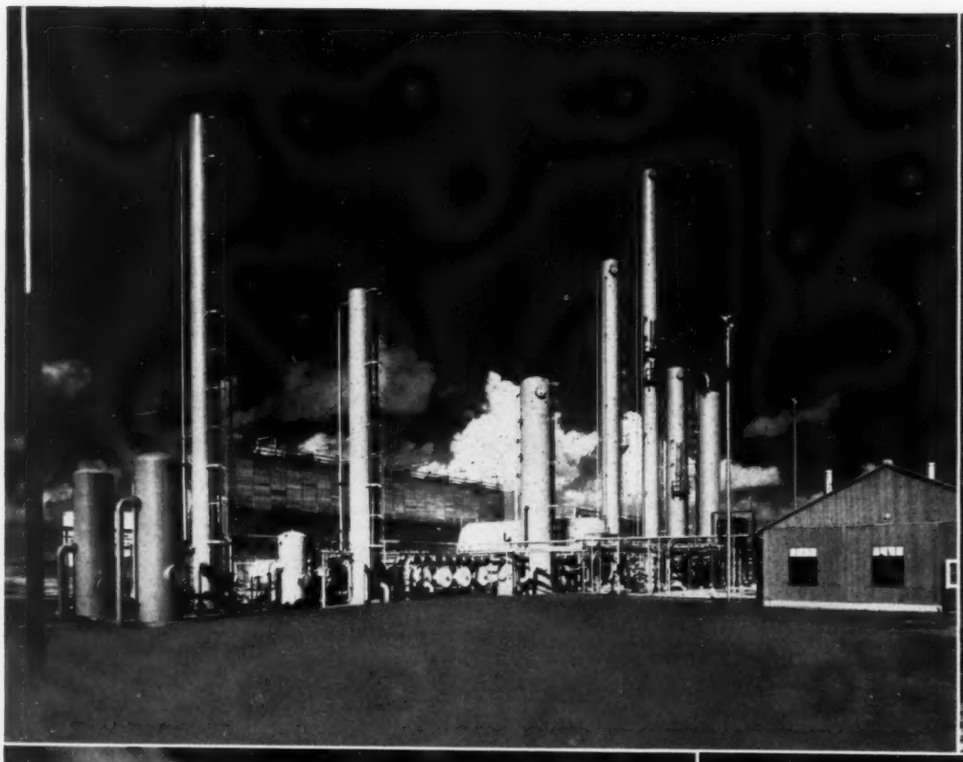
All these new technologies had to be established on very large scales, involving a vast amount of new engineering and construction, much of it on novel lines with which most refiners had little familiarity. And this immense new engineering and construction required immense amounts of new capital. At last accounts the need for the erection of new plants and the enlargement of existing ones has called for the investment of $1,000,000,000 of new capital. Just before the United States undertook in real earnest to prepare for war the oil refining industry was operating on an invested capital of around a billion dollars. Thus, in a little more than one year the refining industry has been called on to double its plant investment in order to implement the new technologies required for oil's share in the national war effort. A large amount of this new capital was privately invested by the industry itself, but the major portion has to be provided by the government.

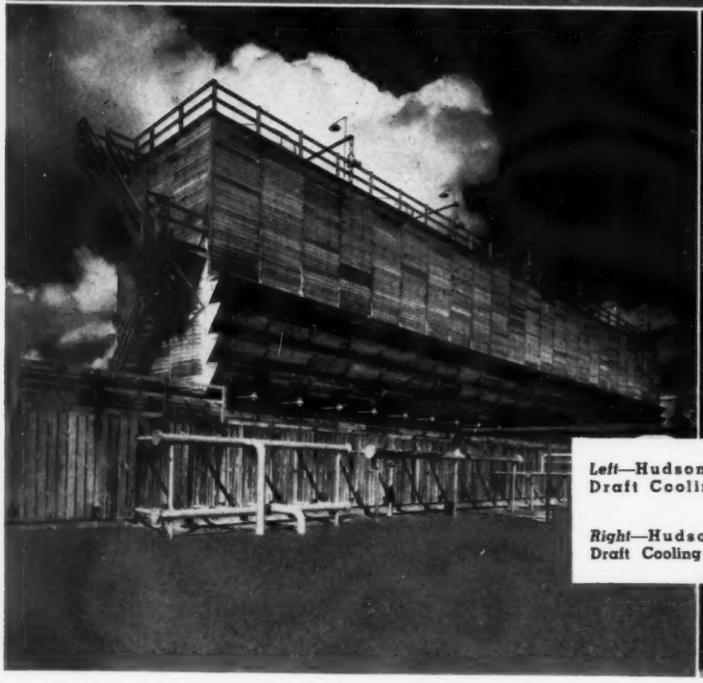
The first objective of the industry's war-time technology was the provision of an adequate supply of aviation gasoline, 91 octane number or better. Estimates of what constituted an adequate supply of aviation gasoline were continually revised upward, until at last accounts they stood at about 250,000 barrels a day, far beyond the industry's capacity in 1941. The immediate effect of the new program was to divert all materials with high octane values into the stocks of 100 o. n. aviation gasoline. At first these values could be had chiefly at the expense of the octane values of motor gasoline, which suffered a decrease of its octane rating that might have been drastic if rationing and tire conservation had not forced a large decrease in the consumption of motor fuel. But robbing motor gasoline of its octanes was not sufficient. New supplies of octane values had to be created. This was at first accomplished by enlarging facilities for producing alkylates and other high quality blending agents, and by intensifying the operations of old and new installations for isomerizing, polyforming, gas reversion, hydroforming, and other means of preparing aviation gasoline base stocks for blending. Aside from these processes the backbone of aviation gasoline production was and still is the process of catalytic cracking originally represented by a considerable number of Houdry installations.

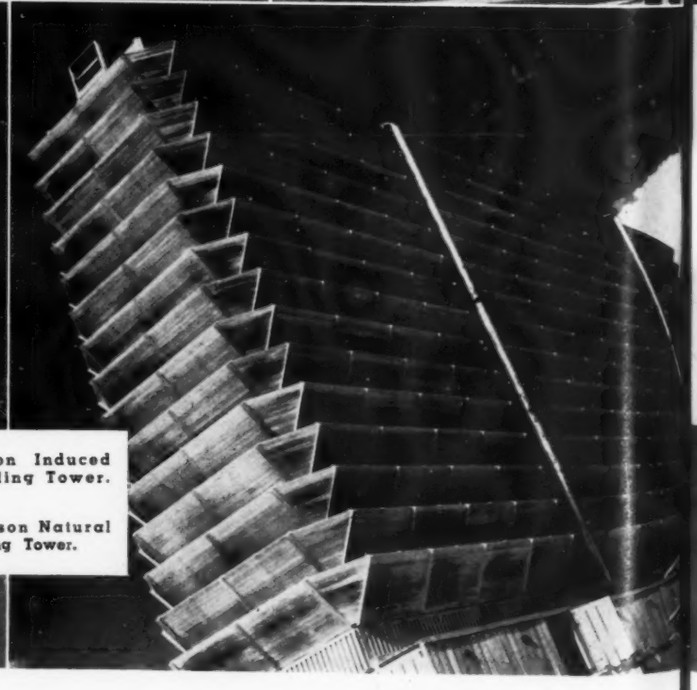
The effort to enlarge the supply of aviation gasoline base stock brought to the front some new technologies in the art of catalytic cracking. Among these, the principle of the "moving catalyst" has come into prominence, particularly in the form of the "Thermofor" process and more

A large capacity, light oil furnace on the Pacific Coast: heavy fuel oil, distillate fuel oil and refinery gases have replaced motor fuel in demand on war time refineries necessitating several changes in refinery balance and the addition of new units.

HUDSON-BUILT PLANTS PRODUCING "Fuels



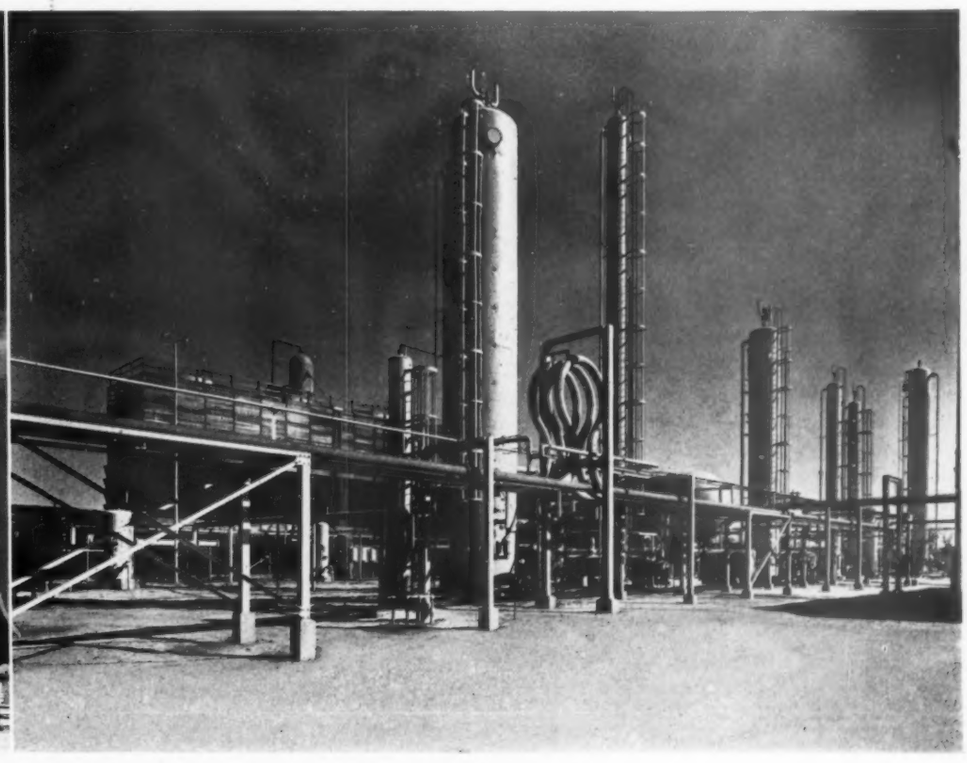




Left—Hudson Induced Draft Cooling Tower.

Right—Hudson Natural Draft Cooling Tower.

for Freedom"



In refineries, distillate fields and oil fields in Texas, Oklahoma, Illinois and Louisiana, Hudson plants or equipment are contributing to the tremendous and constantly increasing flow of fuels for war, including high purity propane, butanes, pentanes, and closely fractionated high octane aviation blending stocks.

To the refining, producing and gas industries we offer the services of an integrated engineering and construction organization qualified by experience to complete, in minimum time, projects of any size—either independently or in collaboration with our client's engineering departments.

HUDSON COOLING TOWERS

With the mind of the refining industry concentrated on increasing the output of aviation gasoline, synthetic rubber bases, alcohol, toluene and other products essential to war—Hudson is ready with:

1. *Experienced Personnel* to promptly offer Cooling Tower recommendations to best meet the particular cooling problem.
2. *Best Possible Delivery* of all materials, usually within 60 days, for large towers.
3. *Fast Field Erection* by thoroughly experienced crews. Towers are prefabricated in our Houston mill, thus minimizing field erection time and making optimum use of skilled labor.

HUDSON ENGINEERING CORPORATION

Engineers and Constructors

FAIRVIEW STATION • HOUSTON, TEXAS

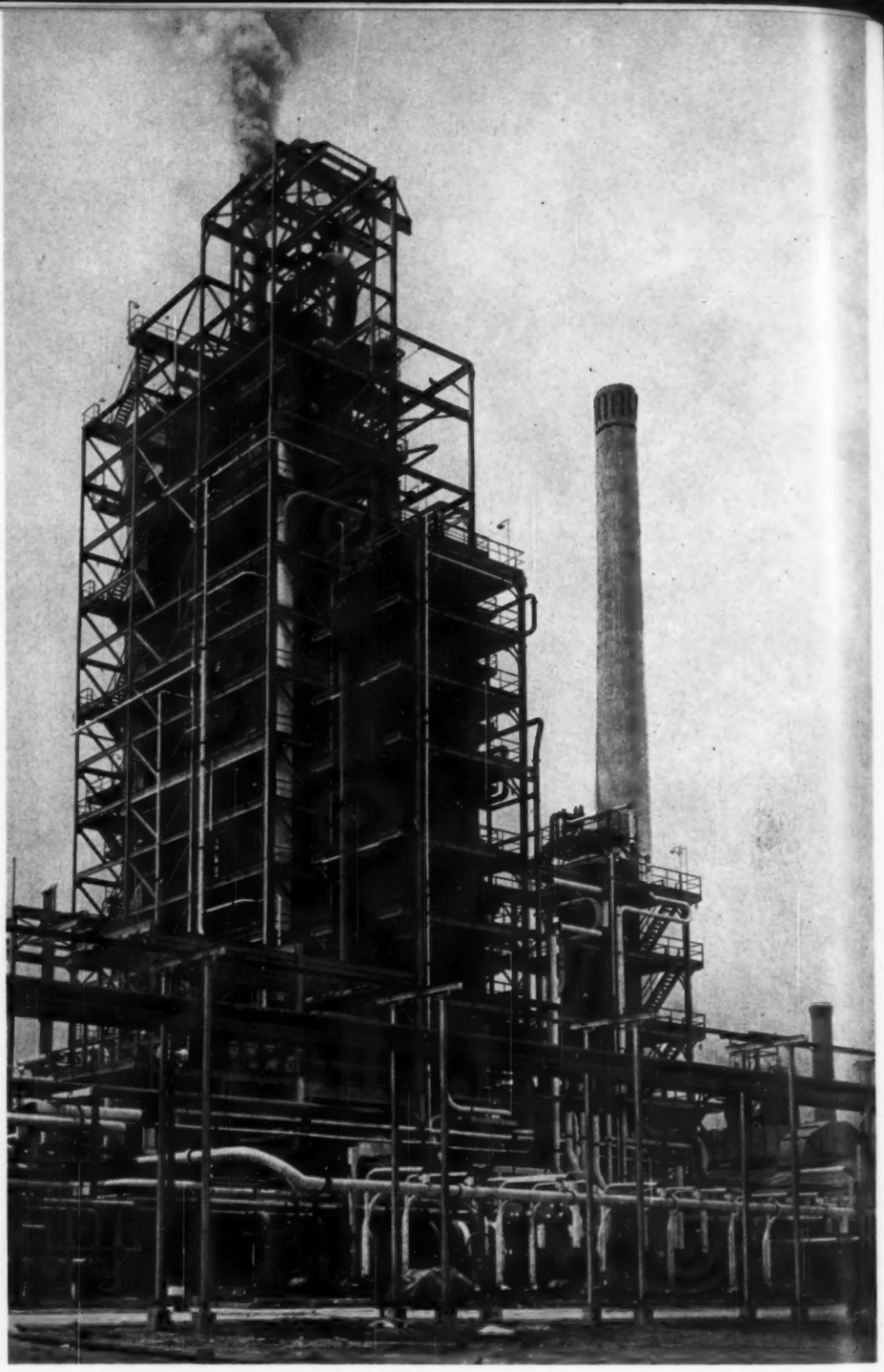
especially in the form of the so-called "fluid catalyst process." To date, around $100,000,000 of new capital has been allocated to the construction of plants to operate according to the last named process; the first of these fluid catalyst plants are now coming into operation, and are said to be functioning well.

The campaign to increase the production of aviation gasoline has not been limited to the creation of new facilities for catalytic cracking. The whole refining industry, which formerly was keyed to the production of 70-85 octane number motor gasoline has now been keyed to produce primarily the 91-100 o.n. grades. What with the decline in consumption of motor gasoline and the awarding of government contracts on the basis of military requirements, all refiners, if they are to operate profitably, must revise their technologies accordingly. This situation has brought about the necessity for small refiners, who cannot provide themselves with self-contained catalytic cracking plants, to pool their resources and raw materials that can go directly into military products. Even so, it has not been possible for every small refiner to participate in the direct supply of war products, and so the refineries are divided into two groups: those with and those without war contracts. However, the government, with laudable intent to save the smaller enterprises, is allocating production so that the smaller units may continue to supply civilian needs.

As was said above, a principal function of the catalytic cracking plants is to furnish aviation gasoline base stock, but the technology of these plants has been greatly complicated by requiring them to contribute to the hardly less important toluene and synthetic rubber programs. The program requires the production of a million tons of synthetic rubber a year, and this objective requires that the rubber manufacturers be supplied with a daily charge of 13,000 barrels of butadiene. Although moves are being made to obtain some of this butadiene from sources outside the petroleum industry, the oil refineries are now the only places where it is being produced. Hence the present technology of catalytic cracking calls for the simultaneous production of aviation gasoline base stock, toluene, and raw material for synthetic rubber. How this balance is achieved is a technical detail that for the time being is shrouded in reticence, but it can be said that it involves numerous factors of catalyst quality, with definite relations between time, volume, temperature, pressure, and nature of charging stock.

The technological problems of catalytic cracking have been further complicated by new developments in the technique of aerial warfare. Not long ago a 100 octane number gasoline was considered sufficient for fighter airplanes, but for combat in the air 100 octane gasoline is now practically obsolete—it does not give enough power for speediest maneuvering. The aim now is an aviation gasoline having octane numbers above 100, which may be up to 125. This high octane rating cannot be obtained with the blending agents heretofore relied on. The necessity of providing these new ingredients has demanded a new refinery technology for their production, either in plants for synthesizing them as a separate operation (as is now being done by Shell), or by an appropriate modification of the technology of catalytic cracking plants.

To date, the new catalytic cracking plants from which will come a major proportion of the butadiene for manufacturing synthetic rubber have not yet come into operation on a scale sufficient to meet the situation, and the industry has been required to scour every possible source from which butane, the parent hydrocarbon of butadiene, can be obtained. This applies especially to natural gasoline plants, and the recycling plants in distillate oil fields. These establishments have been required to apply a more exact technology of distillation, absorption and extraction to make sure that every molecule of precious butane shall



The first of the much discussed fluid catalyst cracking units for the production of aviation gasoline. In addition these units were originally designed to produce relatively small quantities of butadiene for the rubber program; it has since been found that by slight modifications in operation that the output of butadiene can be increased two and a half to three times without affecting the yield of aviation gasoline.

be conserved. This has meant a reduction in the amount of natural gasoline produced and a more or less appreciable reduction in the amount of butane available for giving the usual octane rating to motor gasoline. It has also given a new importance to propane as an alternative source of gasoline vapor, pressure, and also as a charging material for various refinery processes that supply blending material in the form of alkylates and isomates. Instead of being more or less ignored propane is being recovered by a fractionating technique that leaves no more than 0.3 percent in the waste gas.

As was said above, at the moment of writing the existing sources of butadiene for synthetic rubber are far from sufficient and the huge new plants now building will not be ready for some time. To hasten the supply of butadiene the government has surveyed the approximately 450 oil refineries of the country to discover how their working methods might be readjusted so that they may produce more butadiene, preferably without new or at most relatively inexpensive construction. Catalytic cracking is recognized as the best way to produce butadiene, but this hydrocarbon also occurs in larger or smaller quantity as a by-product of thermal cracking. The thermal cracking plants are therefore being called on to revise their cracking technology to whatever extent is found practicable in each case. In view of the national necessity the government has shown a disposition to pay what the product costs in each case, both to obtain what is needed, and to keep the smaller enterprises occupied. In this effort to bring thermal cracking into a field for which it is not especially adapted, new ways of conducting old operations are being adopted which will make interesting reading when they can be made public. Some of these processes which otherwise would not be practicable, are working on "distress" gasoline as a raw material.

Aviation gasoline and butadiene are two of the products that have imposed major changes in oil refining technology. Toluene for military purposes has imposed a third major change. Instead of being obtained as an incidental by-product for sale to paint manufacturers and other users of organic solvents, the production of toluene has been started on a large scale by processes especially designed for the purpose. The estimates call for nitration-grade toluene at the rate of 250,000,000 or 300,000,000 gallons a year; during World War I the peak production was not more than 12 million gallons. At first there was a disposition to rely on separate installations for toluene production. Thermal plants that are real synthetic toluene factories have been built, as for instance Humble's new 30,000,000 gallon toluene plant and a number of others that are nearing completion or are under construction.

However, the technology of catalytic cracking has made enormous strides since December 7, 1941. It is now possible, and apparently economically practicable, to adjust the factors of catalytic cracking: catalyst quality, time, temperature, pressure and volume relations—so as to produce toluene (and other aromatics), butylene, and aviation gasoline base stock in satisfying quality and quantity in a continuous operation. Aside from considerations of emergency, which require that all existing or easily provided facilities be employed for obtaining needed products in the shortest possible time, a modern catalytic cracking plant, with perhaps a few minor thermal auxiliaries, could meet all or most military and civilian demands for refined petroleum products.

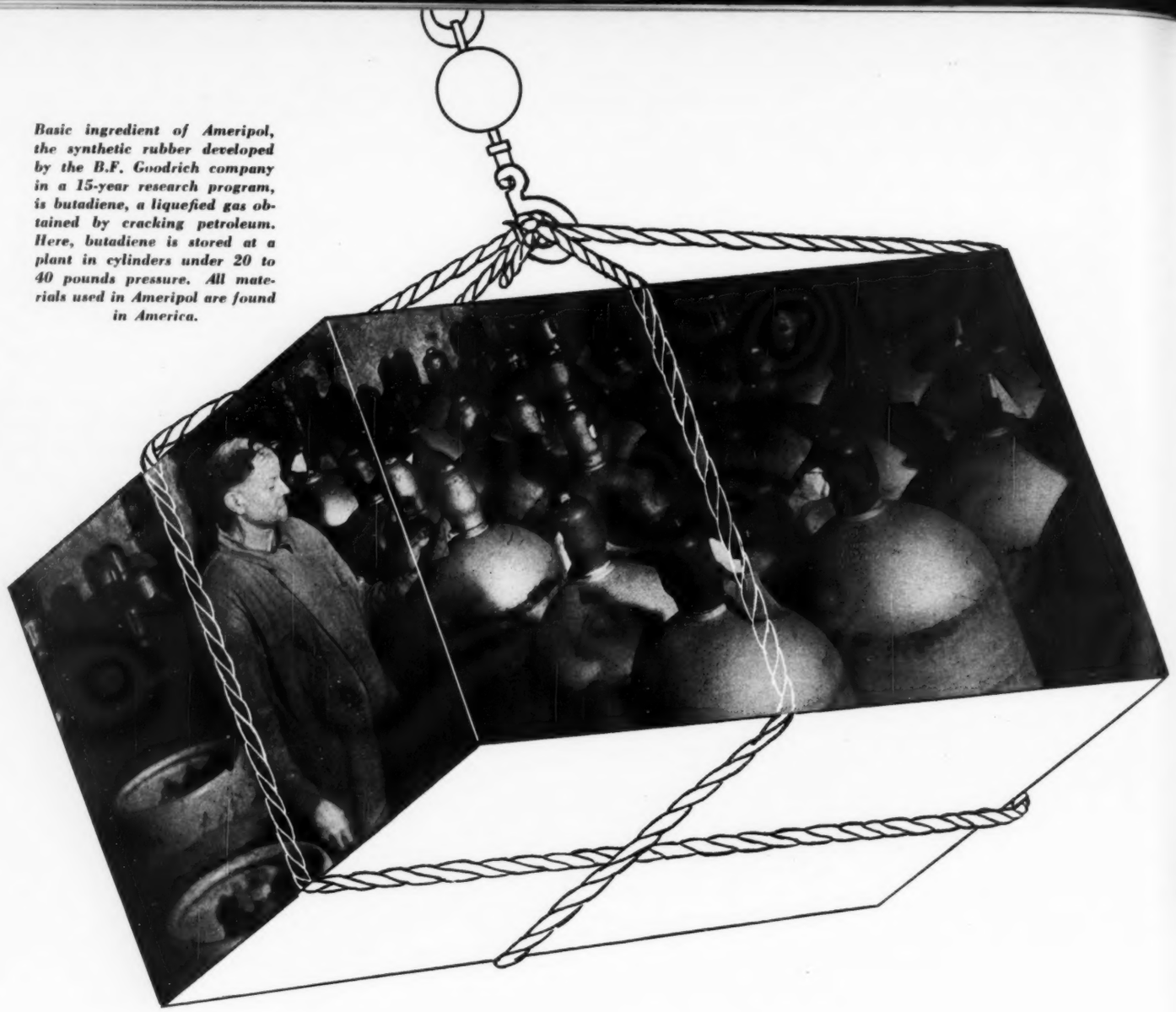
And after the war? When peace comes the oil refining industry will find much of its equipment and capital tied up in technologies more related to war needs than to civilian needs of the pre-war period. A large part of this abnormal investment will have been for government account and will be liquidated with the general tax burden which this and future generations must bear. What will the industry do with its great plant for producing aviation gasoline of 100-plus octane number, when the tens of thousands of war planes are finally grounded, when millions of high explosive shells are not being fired daily, and when (or if) the ships again come laden with natural rubber from the Far East?

It is practically certain that when peace comes the nation's automobiles will again crowd the roads, perhaps in greater numbers than ever, and these automobiles will require as much if not more motor gasoline than they did before the war. In that case the refining industry will resume its normal function of turning most of its crude oil into gasoline for the filling stations. But the quality of post-war gasoline will be different; the industry has now learned how to make better gasoline, and the designers and manufacturers of automobile engines are even now preparing to build engines to run on this better gasoline. Perhaps 100 octane number gasoline will become as standard for everyday use as yesterday's "premium gas" of 75-80 o.n. But this gasoline will be produced only in the refineries that can make it economically, and these refineries will be those with catalytic cracking plants. Such plants will not be "war babies," but all others, including the numerous existing thermal cracking plants which cannot easily make 100 o.n. gasoline, are very likely to be war casualties unless their owners do something about it, with or without the help of the government.

One of the most obvious (at this time) chances of survival open to owners of thermal cracking plants is a continuation of the system developed for them by the OPC. This is the system whereby small refiners who cannot afford expensive catalytic cracking plants of their own may club together and build central 3-way catalytic plants to which they may send their naphthas, gas oils or residuums for catalytic conversion into high octane values for blending with their gasolines.

A further problem that will hang over into the new era of peace will be the fate of the huge installations that have been committed to the production of synthetic rubber. Whether peace will put an end to these enterprises will depend on two contingencies, one technological and one political. If, (as various half-disclosed facts seem to indicate) the production costs of butadiene are markedly lowered and rubber manufacturers succeed in producing a synthetic rubber that is markedly superior to natural rubber, the owners of Far Eastern rubber plantations (whoever they may then be) may find great difficulty in recovering their market. If the new synthetic rubber industry should not perfect its technology to the point where it can defy foreign competition, the old-fashioned American doctrine of tariff protection for American industry might be successfully invoked, particularly if the corn and wheat farmers obtain (as now appears likely) a share in the business of supplying butadiene.

In conclusion it is worth noting that the petroleum industry, by having large new demands thrust upon it, has learned (or experienced) a good deal besides new technologies. One of these is that coordination and cooperation can be of vast assistance in attaining the common objective of serving themselves and their country, particularly in the way of avoiding cross purposes and lost motion, and in the pooling of resources. Under the guidance of the government and particularly the OPC (which is largely manned by members of the petroleum industry itself), the work of producing what the country needs has been divided up and allocated so that each element of the industry has been assigned the part for which it is most capable, and this is being done with the intention that the small refiners shall continue to have a share in the business, even if this is no more than contributing to ordinary civilian needs. The authorities have acted (at least as far as they have been able) to preserve the smaller enterprises and to assure in some measure that the industry will obtain prices that will compensate it. In a word, the industry has been learning something about how to act as a unit, both technically and commercially, and the government has sensed the public benefit of allowing or requiring it to do so. This experience may prove of great help in the new world that will be rebuilt on lines that are sure to depart greatly from old notions of economics and commercial and personal individualism.



Basic ingredient of Ameripol, the synthetic rubber developed by the B.F. Goodrich company in a 15-year research program, is butadiene, a liquefied gas obtained by cracking petroleum. Here, butadiene is stored at a plant in cylinders under 20 to 40 pounds pressure. All materials used in Ameripol are found in America.

CONSERVATION SYNTHESIS AND RECLAMATION COMBINE TO SOLVE UNITED STATES RUBBER SHORTAGE

By E. W. Mayo Jr.

Conservation of Existing Tires Plus Use of Serap Rubber Will Maintain Essential Civilian Mobility Through 1944—MilitaryRequirements Can Be Met From Stocks Supplemented by Growing Synthetic Capacity—By 1945 Position Will Be Stabilized.

"THE RUBBER SITUATION is such that dispute about gasoline should be all but academic. Driving must be curtailed on the basis of the present rubber outlook. Therefore, national gasoline rationing on a sensible basis must be given serious consideration," said the Special Committee Investigating National Defense Program in May of this year. All available evidence indicates that nationwide gasoline rationing to conserve rubber is inevitable if a serious situation in war work is to be avoided; and this condition will prevail regardless of the degree of success achieved by the recently concluded scrap rubber collection drive, or any subsequent program for the collection of scrap rubber. With civilian driving restricted to essential needs and in view of the United Nations rubber stock pile, the development of the synthetic rubber industry and stimulation of South American natural rubber production, there will be ample rubber for military requirements and war industry. For a better understanding of the present situation and the direction in which it is likely to develop in the immediate future, it will be of interest to review the overall situation in regard to natural and

With rubber reclaiming plants receiving scrap rubber at a rat of only 50 percent of their capacity prior to the President's cam paign, John L. Collyer, president of the B. F. Goodrich company urged a "rubber round-up" in every community in the country t boost receipts to the 400,000 tons of scrap needed. This collec tion shows just a few of the rubber items found in cleaning ou the closets in the average American home.

Here is Ameripol, the Goodrich "Liberty Rubber" capable of re placing natural rubber, in the thin sheets required for most stand ard rubber manufacturing operations. The corrugated surface i imparted by the mill roll. At this stage it is flesh-colored, but whe given a final drying becomes clear amber like natural crepe rubber

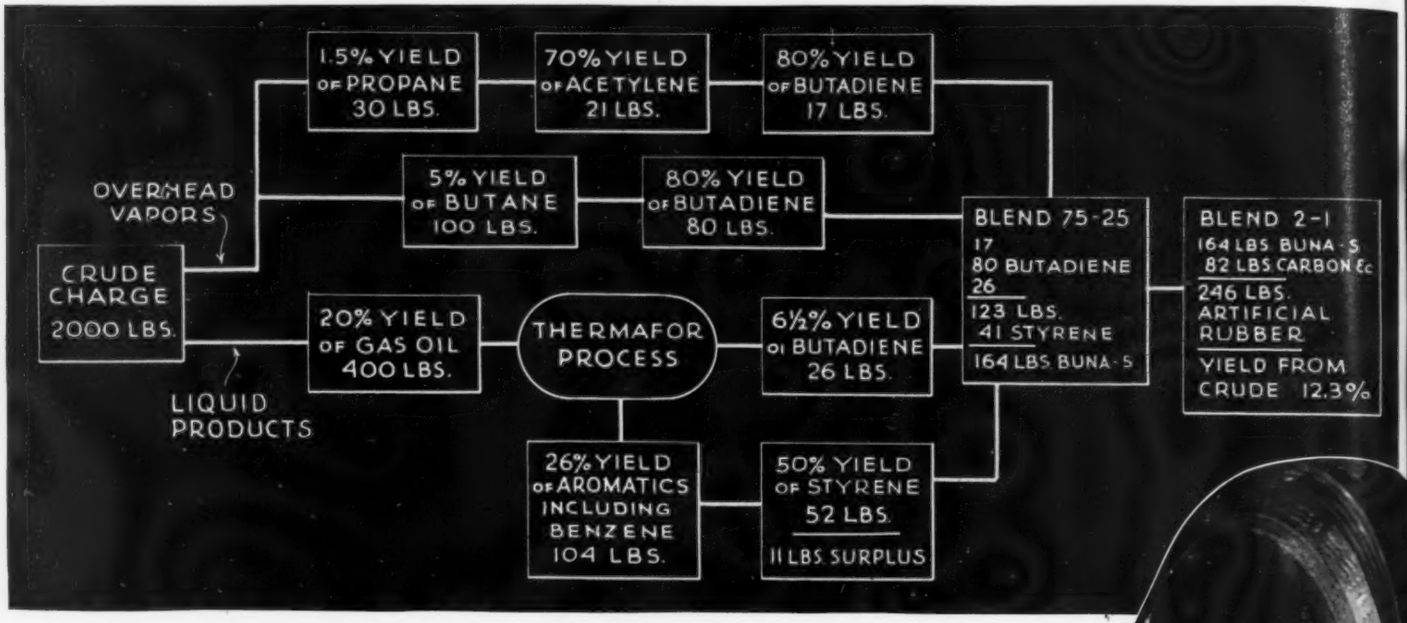
As the campaign to collect scrap rubber draws to a close it i estimated that 400,000 tons have been collected: some system o continuing incentive is needed to assure the return of emergen scrap.

synthetic rubber production, reclamation of rubber scrap, and stocks of crude and manufactured rubber.

As is well known, the major part of the world's supply of natural rubber, although it originated in Brazil, for many years past has come from the Far East. In the latter part of the last century an English scientist succeeded in smuggling a few seeds out of Brazil and experimental plantings were established in British Malaya. From these modest beginnings developed the great rubber plantations of the Far East where high yield cultivated trees tended by cheap native labor produced 96.95 percent of the world's exportable rubber. Of the Far Eastern rubber producing areas those in British Malaya, Burma, North Borneo, Sarawak, Netherlands India, Siam and French Indo China, representing 90.44 percent of the world's exportable crop are in the hands of the Japanese. Ceylon, producing 5.58 percent, India producing 0.93 percent and the production of Africa, Central and South America accounting for the remaining 3.05 percent represent sources that are still available to the United Nations. There are, of course, extensive plans to increase the production of these areas controlled by the United Nations, which in 1940 produced some 133,059 long tons compared with the 1,258,775 long tons produced in the areas now controlled by the Japanese. These plans are reviewed in detail on the following pages.

In 1922 world production amounted to approximately 400,000 tons and the lowest New York spot price was 11½ cents per pound in comparison with prices ranging from 50 cents to $1.00 per pound in the years immediately preceding. As a consequence of these low prices, British and Dutch interests adopted the so-called Stevenson Plan in 1922 whereby licenses were required for the export of rubber and machinery was established for controlling exports to sustain world prices. This plan continued in effect from 1922 to 1928 substantially strengthening prices, at least in the earlier stages. In 1928 the Stevenson Plan was discarded and by 1932 spot rubber prices in New York had reached an all-time low of 2⅝ cents per pound; the highest price quoted on the New York spot rubber market that year was 4¾ cents per pound. British and Dutch rubber interests organized the International Rubber Regulation Committee in 1934 for the purpose of stabilizing world prices at more profitable levels. This Committee, which has continued to function until the present time, regulated planting and controlled the amount of rubber that could be produced for export; in this way prices could be maintained at profitable levels while the committee could take appropriate steps to prevent the commercial development of a seriously competitive rubber industry in any other part of the world. The activities of the International Rubber Regulation Committee are important because, in a sense, it prevented the building up of stocks in the United States that might have been considered excessive in 1939 but which would scarcely be adequate under existing circumstances. Indirectly the Committee's activities prevented the development of a vigorous synthetic rubber industry on a purely commercial basis; such work as was done in this direction being paid for out of the research funds of oil and rubber companies. For development of an actual commercial industry, these companies had to rely on government subsidies which were delayed in the United States until after the outbreak of the European war.

As far back as 1932 the Army and Navy Munitions Board declared rubber a strategic material and more recently urged the development of a synthetic industry, building up of domestically held stocks and conservation in the use of rub-



A generalized chart indicating very roughly the yield of synthetic rubber from a given quantity of crude oil: the yields shown vary widely depending on the type of crude charged and the process used.

ber that was already in hand. However, in 1938 the International Rubber Regulation Committee restricted the production to 45 percent of capacity, raising this to 60 percent in 1939 and 83 percent of capacity in 1940; by November, 1940 the Committee increased the quota to 100 percent of capacity but this did not become effective until 1941. During these years the Committee had restricted exports to 55 percent of the 1,335,250 ton 1938 crop; the following year export quotas were increased to 58¾ percent of the 1,519,000 crop and in 1940 to 83¾ percent of the 1,541,550 ton crop. The Rubber Reserve Corporation, a subsidiary of the RFC under the direction of Jesse Jones, began to build up the United States rubber inventory in June, 1940 and at that time urged the Rubber Regulation Committee to increase quotas all along the line to permit much larger exports to the United States. For 1941 the Committee increased the export quota to 105 percent of the 1,554,700 ton crop and increased plantings to produce an anticipated output of 1,563,000 tons in 1942. The Rubber Reserve Corporation had contracted to purchase all rubber available for export except those quantities purchased by private U. S. rubber companies.

In appearance Goodrich's finished Ameripol tire, first automobile casing to be made entirely from American materials, is identical with the everyday product. Sidewalls and tread are of Ameripol, while all other materials such as cotton cord fabric, bead wire, and carbon black are just like those used in natural rubber tires.

Although the Rubber Reserve Corporation had begun to accumulate an inventory in June, 1940, there were no restrictions on the consumption of rubber in the United States and the shipping situation was becoming constantly more difficult. By the end of 1940, after six months of operations, Rubber Reserve had acquired 40,143 tons and the U. S. manufacturers had on hand 143,569 tons. In June, 1941 the first restrictions on consumption were imposed and the Rubber Reserve became the sole purchaser of imported rubber. U. S. consumption of rubber which had amounted to only 563,710 tons in 1939 had reached the unprecedented rate of 900,000 tons per year during the first half of 1941 before the restrictions were imposed. Actually during the whole of 1941 a total of 766,000 tons of rubber were consumed in the United States. Then, on December 10, 1941, three days after the attack on Pearl Harbor, the sale of tires to the public was stopped and in February, 1942 restrictions on the sale of all rubber goods were made fully effective. By March of 1942 the Rubber Reserve had acquired 342,101 tons which added to the stocks frozen in manufacturer's hands gave the United States a reserve of approximately 700,000 tons.

The normal world situation may be summarized as follows: U. S. peacetime requirements are about 600,000 tons per year of which 72.4 percent goes into tires, 7.7 percent into mechanical uses, 5.9 percent into footwear and 3.2 percent into wire and cable; the balance being used for miscellaneous purposes. Great Britain, the British Dominions and India consume approximately 190,000 tons per year. Russia depends primarily on her domestic synthetic industry but under wartime conditions must import limited quantities from the United States under provisions of the lend-lease arrangement. It has been estimated that the German army, supplied from the German synthetic industry, requires approximately 200,000 tons per year; American military requirements have been figured at 271,000 tons in 1942 and 393,000 tons in 1943. Leon Henderson, testifying before the Truman Committee presented figures to show that the United Nations started the year 1942 with 706,000 tons of rubber to which will be added 453,000 tons of crude and 28,000 tons of synthetic production in the United States plus 54,000 tons of synthetic production in the Soviet Union yielding a total supply of 1,241,000 tons. Against this supply is placed military demand of 271,000 tons, lend-lease exports of 82,000 tons, minimum civilian requirements of 150,000 tons and minimum consumption in other United Nations of 310,000 tons, all requirements totalling 813,000 tons leaving a carry-over of 428,000 tons in 1943. Mr. Henderson figured that the new supply of crude rubber in 1943 would amount to 61,000 tons but that synthetic production in the United States would by then be 300,000 tons and in Russia synthetic production would have reached 71,000 tons, or a total United Nations supply in 1943 of 861,000 tons. Against this would be placed military requirements of 393,000 tons, lend-lease and other United Nations requirements of 353,000 tons and minimum civilian consumption in the United States amounting to 120,000 tons. Total demand would be 866,000 tons for 1943 against total supplies of 861,000 tons, or a deficit of 5,000 tons.

Several investigations of the remaining sources of natural rubber supply available to the United Nations have been made and reveal approximately the following picture: 8,000 tons of Mexican guayule, up to 20,000 tons of wild rubber from Central and South America, up to 20,000 tons of cultivated and wild rubber from Africa and 77,664 tons of cultivated rubber from Ceylon are available for export. Guayule, when cultivated requires one year of development in the nursery and then from four to seven years in the field. Hence it would have little bearing on the supply situation during the war and can be written off except for the guayule now gathered in Mexico and processed in four existing plants in that country. Normally about 4,000 tons of guayule are imported into the United States from Mexico and there is reason to believe that this figure could be increased to 8,000 tons. While guayule is inferior to the natural hevea rubber, it can, no doubt, find a minor place in the industrial picture releasing other supplies for more exacting service. Brazil, the home of the rubber industry during the last century, has signed an agreement with the Rubber Reserve Corporation whereby the latter will purchase Brazil's entire exportable surplus at 39 cents per pound, f.o.b. Belem and will pay bonuses for quantities in excess of 5,000 tons. Rubber Reserve is also spending $5,000,000 in Brazil to stimulate the production of rubber on a relatively short term basis. A similar agreement was signed on July 2 with Colombia where Rubber Reserve will spend $1,000,000 in developing production. President-elect Lopez, in the United States on a visit prior to his inauguration on August 7, expressed the opinion that a much larger supply of rubber would be found in Colombia than earlier superficial surveys had indicated. Similar agreements

are being negotiated with Peru, Bolivia, Ecuador, Venezuela, Mexico, Nicaragua and Guatemala. While Central and South America exported 17,500 tons of rubber in 1941 it is not anticipated that this source can greatly increase its shipments since domestic requirements in South America are bound to increase rapidly with the drying up of former sources of supply. It has been estimated that exports might reach 20,000 tons next year but probably will not go much above this for several years. The plantations that have been established in Brazil are still in the nursery stage, the Ford plantation being the most advanced. It expects to ship, perhaps 1,000 tons during 1942 and will not be in substantial production until 1950. In Africa, the Firestone plantation is now producing and some rubber is available from wild trees; altogether some 20,000 tons may be exported from Africa in 1943. Ceylon production has already been mentioned.

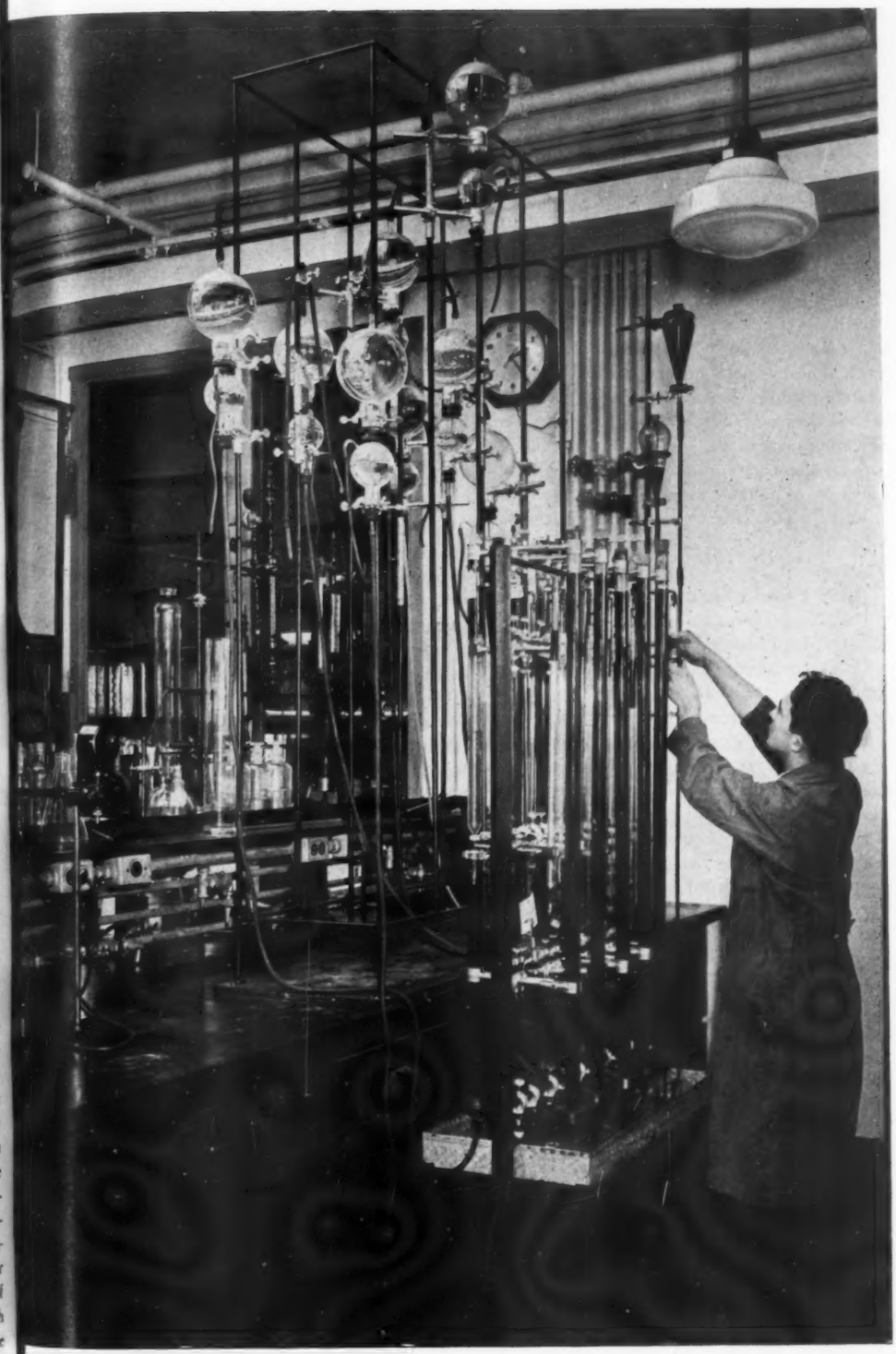
Actually the natural crude rubber outlook for the next few years is not encouraging. There may be available some 133,000 tons for the United Nations but this rubber will be rigidly restricted to military use as will the United Nations' stock pile amounting to 706,000 tons. There remain two other major sources of supply that may eventually be available for civilian consumption, at least in the essential use category: reclaimed rubber and synthetic rubber. In addition there is an inventory represented by manufactured rubber now in use, primarily tires on passenger cars and trucks. In an article in the July issue of WORLD PETROLEUM reference was made to 126 million passenger automobile tires in the United States. Broken down according to age and approximate condition of these tires as far as it could be determined statistically, it was estimated that these tires had a potential of 318,720 million vehicle-miles. By gasoline rationing on a nation-wide basis it would be possible to eliminate 2,000,000 of these cars from the road and by arrangements through appropriate government agencies, the tires on these cars could be distributed to essential users. Another 5,000,000 cars could be reduced in mileage from the normal 9,000 miles per year to 2,000 miles per year and the remaining 20,000,000 cars, which it has been estimated are essential to maintain required industrial and agricultural mobility, could be reduced in mileage by 30 percent. Altogether the essential vehicle-miles under these restrictions could be brought down to 145,000 million which would extend the operating life of the essential 20 million cars to the middle of March, 1944. Mobility could be maintained for some time after this by the injection of reclaimed rubber into the total tire mileage potential; and eventually the synthetic rubber program would reach a point where it could, at least, meet military and essential civilian needs.

Opinions as to the amount of rubber that can be collected differ widely; at the time of writing the first scrap rubber collection campaign is still in progress and no figures as to final results are available. However, it is possible to form some idea of the amount of scrap rubber in existence, although how much of it can be gathered in and reprocessed depends on a number of indefinite factors. In an able analysis of the scrap situation Dr. Joseph E. Pogue of the Chase National Bank points out that over the past ten years the United States has consumed 4,794,000 tons of crude rubber and of this total 1,289,000 tons has already been reclaimed. This eliminates at once all the fantastic estimates of 10,000,000 tons of reclaimable scrap that have found their way into print. It appears, therefore, that over the past ten years some 3,500,000 tons of rubber are unaccounted for; obviously some of this has been used up on the roads of the nation; some has been destroyed; and some has been so widely dispersed that it would be impractical to retrieve it. At the outside probably not more than 1,000,000 tons could be gathered in, but if everything obtainable were brought in there is no indication that anything like this quantity will be collected in the first drive. Dr. Pogue suggests that more scrap collections will be necessary to secure what he refers to as the "historic scrap" and that some form of continuing incentive will be necessary to insure a constant return flow of "emergent" scrap; that is the scrap that is constantly being generated as tires wear out. To obtain any quantity of historic scrap some guarantee that the price will remain stable might be helpful; in the case of emergent scrap some system of certificates will no doubt be worked out enabling a motorist to obtain the right to purchase a recapped tire in place of scrap tires that he turns in.

In the first scrap rubber collection drive, Leon Henderson has estimated that about 300,000 tons of reclaimable rubber will be secured; the War Production Board believed that as much as 700,000 tons might be collected. Since the total reclaimable rubber in existence in the United States is not over 1,000,000 tons and in view of the foregoing estimates it may be assumed for convenience in calculating that perhaps 400,000 tons will be collected. At least 15 percent of this is lost in processing leaving 340,000 tons of usable reclaimed rubber. Between 5 and 6½ pounds of reclaimed rubber are used in recapping a single tire; hence it would be possible to recap 120 to 150 million tires. These recapped tires cannot render the service that is expected from a new tire, recaps being good for 5,000 to 8,000 miles against the 20,000 to 30,000 miles expected of new tires. Hence the 120-150 million recapped tires that can be made from 400,000 tons of scrap rubber are equivalent to 30 to 40 million new tires. Normal annual consumption of new tires in the United States is just under 40 million so scrap rubber may prove the solution of the rubber problem for at least an additional year. Of course, many of the recapped tires emanating from this source would be required for the rapidly expanding military establishment; and not all of the remaining scrap rubber would be available for automobile tires. It was estimated in the article referred to above that present tires on the passenger cars in the United States under restrictions imposed by nation-wide gasoline rationing would be adequate to maintain essential mobility to the middle of March 1944; the recapped tires as estimated above, taking into consideration the fact that not all of the 400,000 tons of scrap would be available for tires, might extend the potential mobility of passenger cars to the end of 1944. In fact, the Advisory Subcommittee on Rubber Conservation of the PIWC has estimated that careful conservation of existing tires supplemented by the recapping program could keep 22 million passenger cars in operation until the end of 1944. By that time the synthetic rubber production program should have developed to a point where it could take up any slack.

Research into the molecular structure of rubber and attempts to synthesize material having similar properties was confined to the laboratory until the first world war. At that time Germany found it necessary to attempt large scale commercial production of synthetic rubber. Their industry at that time was based on dimethyl butadiene derived from acetone and was both expensive and unsatisfactory as to quality; production of upward of 300 tons per month was achieved before the end of the war. Thereafter commercial production of synthetic rubber was abandoned until the operation of the Stevenson Plan applied to exports of natural rubber advanced prices to a point where it was considered expedient in Germany to revive experimentation with a view to commercial production. This led to the manufacture of the necessary raw material—butadiene—from limestone and coal via the calcium carbide and acetylene route. While this process proved expensive and laborious it depended on two materials with which Germany was well equipped and is the fundamental system on which the Germans still rely. At the outbreak of the war in 1939, Germany had one synthetic plant completed at Schkopkau for the production of 25,000 tons per year and another plant almost completed for the same capacity at Huels. Since then production has undoubtedly been increased to 100,000 tons or more per year. In the Soviet Union experimentation had been carried on leading to the production of butadiene from catalytically treated alcohol vapors which proved to be a simpler and more direct system than the one employed in Germany. Russia was said to have developed synthetic rubber capacity of about 50,000 tons per year at the outbreak of the war but the present position is obscure since the necessary alcohol was derived from sugar beets raised in the Ukraine, an area now in the hands of the Germans. In the United States, research was directed to developing an artificial rubber with special properties that would improve its performance characteristics over those of natural rubber for certain specialized applications. A number of such specialties were actually developed which were able to compete with natural rubber despite the higher cost of manufacture.

Recent events have entirely changed the outlook for synthetic rubber in the United States and the present aim is to secure large scale production of a rubber substitute that will replace natural rub-

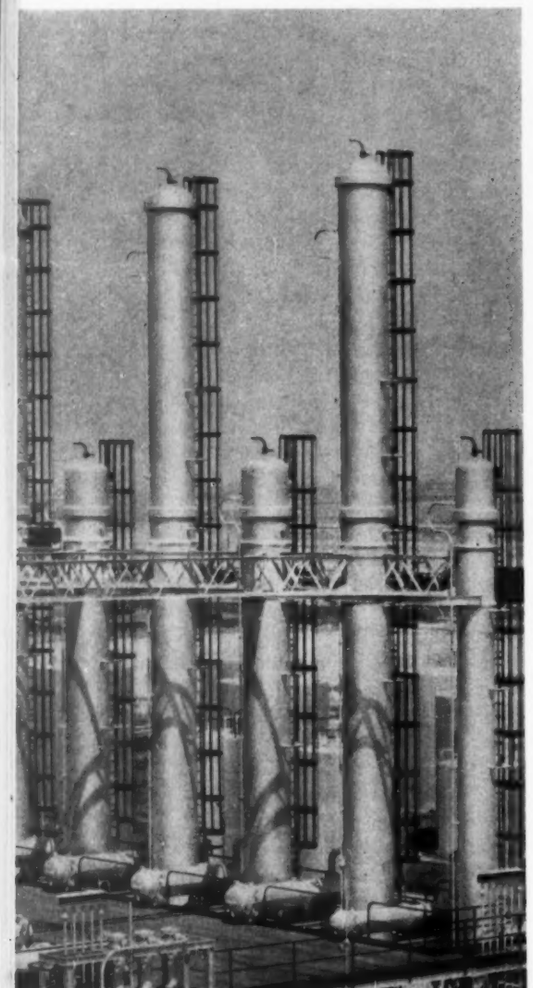


Modern petroleum research requires laboratory equipment that is complicated and expensive; but such research has placed the U. S. petroleum industry in a position to supply the huge quantities of 100 octane aviation gasoline, toluene and butadiene required for the war effort.

ber in all respects—and in the shortest possible time. At present attention is concentrated primarily on three types of artificial rubber: Buna S, Buna N (Perbunan) Butyl and to a more limited extent on Neoprene. At present writing Buna S is the main reliance for an artificial rubber that most nearly meets the requirements for tires. It lacks a little of the stretch and bounce of natural rubber, but on the whole it has enough of both to leave not much to be desired. It is compounded of two principal ingredients. One of these is butadiene, a gaseous hydrocarbon that (given the necessary factory equipment) can be obtained in unlimited quantities from natural gas and other hydrocarbon products that are produced in all the 450 oil refineries of the United States. The other ingredient of Buna S is a hydrocarbon named styrene, which itself is compounded of two other hydrocarbons, ethylene and benzene. Both of these are produced in many oil refinery processes, though the coal tar industry is in a position to supply a considerable quantity of benzene. Given a supply of butadiene and styrene, the work of combining them to make Buna S is a matter of standardized rubber factory routine.

The second artificial rubber on the program is Perbunan, which is called for in much less quantity than Buna S. This variety of artificial rubber is distinguished for its ability to stand up under circumstances where natural rubber or Buna S would soon fail. This is especially the case in and around greasy machinery. It also has excellent aging properties and fatigue resistance; it has high tensile strength, fatigue resistance, and will resist abrasion when compounded with carbon black. The raw materials of Perbunan are again the same butadiene that is used for Buna S, but instead of compounding butadiene with styrene the Perbunan manufacturer compounds it with acrylonitrile which itself is compounded of ethylene (an abundant hydrocarbon) and hydrogen cyanide (better known as prussic acid) which is produced in chemical factories. The compounding of butadiene and acrylonitrile is done in the rubber factory. The third item on the program, Butyl rubber, is also of minor importance from the quantity standpoint. This product does not quite equal Buna S for tire purposes, but it excels natural rubber for many purposes on account of its excellent electrical properties, resistance to oxygen, ozone and aging, to air and to strong acids and oxidizing chemicals. The manufacture of Butyl rubber requires the same butadiene as Buna S and Perbunan, which for making Butyl rubber is compounded with isobutylene, another hydrocarbon that is obtainable in large amounts from oil refinery products and natural gas. It is perhaps the easiest of the artificial rubbers to manufacture.

The fourth principal artificial rubber is Neoprene, a specialty product the principal ingredient of which is acetylene, a hydrocarbon that can be produced from oil refinery products, but is now principally made by chemical concerns. This acetylene is combined with hydrochloric acid to



Shell Chemical Company's fractionating columns used in the manufacture of alcohol from petroleum gases; this alcohol can eventually be used in the manufacture of synthetic rubber.

form a substance known as chloroprene: when chloroprene is emulsified and polymerized the result is Neoprene. This variety of artificial rubber has considerable resemblance to Perbunan, and has found extensive use in making hose for handling oils and gasoline. Developments leading up to the present program for war production of synthetic rubber in the United States started in 1925 when Dr. Waldo L. Semon initiated a research project in the B. F. Goodrich laboratories on this problem. By 1938 the work had progressed to a point where the company was prepared to erect a pilot plant for further experimentation. In 1940, a small commercial plant was built for a capacity of 2,000 tons per year of a butadiene copolymer synthetic rubber. Blended with 50 percent natural rubber this synthetic was made into tires under the trade name of Ameripol and offered for sale at a price some 30 percent above that commanded by natural rubber tires at that time. The premium price was based on better wearing qualities and the commercial acceptance of these tires made it possible for the Hycar Chemical Company (B. F. Goodrich and Phillips Petroleum Company) to test tires made with only one ounce of natural rubber. These tires are said to have given satisfactory service comparable with that expected of natural rubber tires.

Paralleling the Goodrich development, Standard Oil of New Jersey had interested itself in the problem of synthetic rubber having acquired from I. G. Farbenindustrie, leading German chemical company, an interest in the hydrogenation process. Jersey had secured an 80 percent interest and full control of this process outside Germany and of all other refining processes that I. G. Farben might develop before 1947 in return for a payment of $30 million and an option on the control of any purely chemical inventions that Standard might develop during that period. Any processes that might be developed by either party to the contract for production of chemical products from petroleum would be controlled by the inventor with a 3/8 interest for the other party. From the patents secured in this transaction Standard developed processes for the production of 100 octane aviation fuel, toluene and butadiene; the fluid catalyst process also developed from these patents. Rights under the basic patents were made available to a group of 18 American oil and chemical companies in a cross licensing agreement in 1930; in 1931 a half interest in the hydrogenation process was sold to Royal Dutch Shell for exploitation in countries other than the United States and Germany; in 1938 Standard, through its subsidiaries, entered into a contract with the French Government to produce high octane fuel by hydroforming which was a development growing out of the hydrogenation patents acquired from I. G. Farben. In 1937 Jersey Standard working with M. W. Kellogg, Indiana Standard, The Texas Company, Universal Oil Products, Royal Dutch Shell and Anglo-Iranian developed the fluid catalyst process from the hydrogenation process; fluid catalyst was destined to play an important part in the early stages of the subsequent synthetic rubber program for the United States.

It had been found while Standard and I. G. Farben were conducting research on Buna that the original product was unsatisfactory due to the difficulty experienced by rubber companies supplied with samples in milling the product; and because of the uneconomically high cost in comparison with natural rubber of which there was, of course, an ample supply. Nevertheless Buna, particularly Buna-S gave promise for the future and on the outbreak of the European war Standard acquired complete ownership of the Buna process for the United States, the British Empire and France by yielding to I. G. Farben the rights for this process in the rest of the world. By January 1940 Standard had completed plans for a small Buna plant having a capacity of 1,000 tons per year to be erected at a cost of $671,000 to be furnished from the company's research funds.

As the world crisis became graver the Army and Navy Munitions Board interested itself in the development of synthetic means of producing rubber which several years before they had declared a strategic material. After a number of plans had been drawn up for the organization of an industry to produce 100,000 tons more or less (the Munitions Board had specified 15 percent of normal requirements—105,000 tons) the Reconstruction Finance Corporation evolved a plan for the production of 40,000 tons of synthetic rubber. Jersey Standard was authorized to proceed with the construction of a plant to produce one-third of the required butadiene. RFC's original plan had called for the production of 2,500 tons per year of synthetic rubber by each of the following four companies: Firestone, U. S. Rubber, Goodyear and Goodrich. The planned output of these plants was later raised to 10,000 tons each and subsequently to 15,000 tons each. Three of these plants are expected to be in production before the end of this summer; the fourth will be completed by the end of the year. Final RFC plans call for 700,000 tons of Buna rubber capacity to be built by Firestone, U. S. Rubber, Goodyear and Goodrich; 40,000 tons Neoprene capacity to be built by duPont and 60,000 tons of butyl capacity to be built by Standard of Louisiana and Humble. Further studies are being carired on looking to the construction of an additional 200,000 tons of synthetic rubber. These plans embrace only the polymerization of butadiene to rubber; the source of the butadiene has not been finally planned in all cases.

There are three broad divisions of the processes by which butadiene can be produced from petroleum and at least one by which it can be produced from alcohol. Others are undoubtedly in the development stage and may enter the picture in the near future. Butadiene may be produced from petroleum by the fluid catalyst process, the movable bed catalyst process, or by conversion of thermal cracking plants already in existence throughout the United States. The

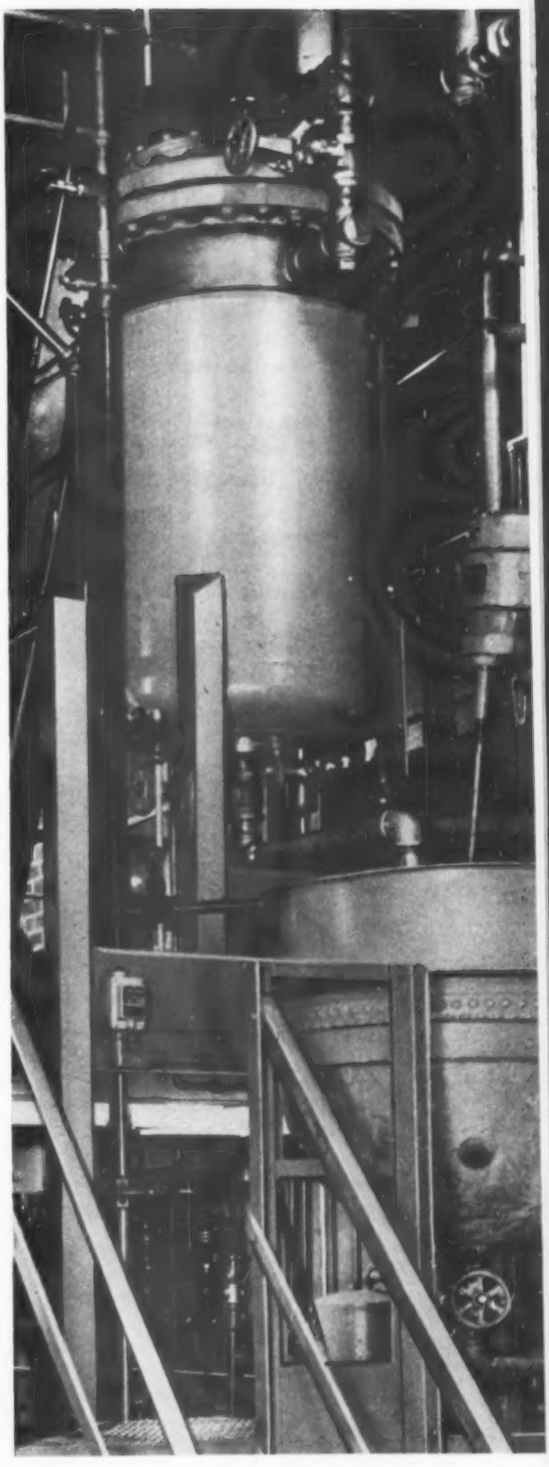
existing program calls for plants to produce butadiene for 400,000 tons of the 700,000 ton rubber program by the fluid catalyst process. An additional 200,000 tons of the program is to be produced from alcohol. The remaining 100,000 tons has not yet been finally allocated between movable bed catalyst and revamping existing thermal cracking units. In fact, the entire program is again under review and plans may be radically changed in regard to the means of producing butadiene from petroleum.

The fluid catalyst process has the considerable advantage of producing 100 octane aviation gasoline and toluene as well as butadiene. As originally set up the demand for these war products had to be balanced between production of large quantities of 100 octane and relatively small quantities of butadiene; or an increased output of butadiene at the sacrifice of some 100 octane production. However, on May 21, 1942, W. S. Farish, president of Standard of New Jersey, announced that fluid catalyst plants could be operated with a slight modification in technique to yield an improved quality of 100 octane plus as much as three times the quantity of butadiene originally anticipated. The improvement in quality of the 100 octane had the following effect: specifications for this fuel produced by the original fluid catalyst process called for performance under rich mixture conditions equivalent to iso-octane plus 1 cc. tetraethyl lead; utilizing the new technique this fuel performs equivalent to iso-octane plus 1 8/10 cc. TEL. This improvement in performance is, of course, highly important under conditions of aerial combat. Against these advantages must be set the fact that very little fluid catalyst capacity is as yet in existence; a few plants are practically finished but none are yet in operation. The building of these units involves at least 18 months time and may extend even longer; they are complicated chemical plants and after construction is complete some time may elapse before they can be brought on stream. Moreover, they require rather large quantities of alloy steels and other critical materials. In view of these considerations, particularly the time factor, there may be some modification of the present plans for furnishing raw material for half the rubber production from this process.

The second major division of process types available for production of butadiene is the movable bed catalyst discussed in detail elsewhere in this issue. Time of construction and requirements for critical materials are substantially less than needed for similar fluid catalyst capacity but yields are not as high if all three war products are considered: toluene, 100 octane fuel and butadiene. At the present critical stage of the rubber program the speed with which these plants can be erected is a major consideration. At the time of writing no movable bed catalytic plants are included in the official rubber program but considerable study is being devoted to this process.

Finally much consideration is now being given to revamping existing thermal cracking plants for the production of quick butadiene and quick synthetic rubber. In favor of this method it is claimed that it would require a minimum amount of critical material and could be accomplished by a revamping of plants already built with a consequent substantial saving in time. Certain thermal cracking processes are known to give high yields of refinery gases that formerly placed them at a disadvantage in the competitive situation but that would now be a marked advantage in view of the changed product requirements brought about by the conversion of the petroleum industry from a peacetime to a war industry. Production of 100 octane aviation fuel and toluene is perhaps less efficient by the use of revamped thermal crackers than by either of the catalyst processes; but the fact that over 1,500,000 bbl. of charging capacity is now in existence and can be put to work immediately weighs the scales heavily in favor of adopting this system for at least part of the synthetic rubber raw material source.

At present the situation may be summarized as follows: production of synthetic rubber at the end of 1942 will be of the order of 95,000 tons per year to be increased to 800,000 ultimately. Studies are now being carried on by the RFC regarding the advisability of raising ultimate synthetic rubber capacity to a total of 1,000,000 tons per year. Rubber Reserve Corporation planned at the end of June 1942 for the construction of 700,000 tons of Buna type rubber capacity to be handled by Firestone, Goodyear, Goodrich, and U. S. Rubber; 40,000 tons Neoprene capacity entirely in the hands of du Pont and 60,000 tons Butyl capacity constructed and operated by Standard of Louisiana and Humble Oil and Refining Company. The butadiene and styrene required as raw material for this rubber output is to be furnished by about 20 oil and chemical companies from catalytic and possibly revamped thermal cracking units. Of the four big rubber companies Goodyear expects to have 15,000 tons capacity in operation by the end of July, 1942; Firestone and U. S. Rubber anticipate operation of 15,000 ton plants in each case by the end of September 1942; and Goodrich will have a 15,000 ton plant in operation by December 1942. Goodrich already is operating a 7,000 ton plant which is in addition to the 15,000 tons capacity that will be ready in December. du Pont has in operation about 20,000 tons capacity for production of Neoprene. Six or seven thousand tons capacity for production of various specialties was in existence before the Rubber Reserve Program was initiated. The United States should go into 1943 with a synthetic rubber capacity of close to 100,000 tons; it is expected that during 1943 300,000 tons of synthetic rubber will be produced although at the moment this figure appears optimistic. During 1944, the synthetic program calls for production of not less than 700,000 tons. By 1945 the situation should have become stabilized with the production of synthetic rubber ample to take care of military, export and essential civilian requirements.



In this control plant of the Naugatuck Chemical Division of the United States Rubber Company, synthetic rubber has been manufactured since January, 1941. This small plant was erected to act as a guide for the large synthetic rubber plant now nearing completion.

BOTTLENECKS and Scarce Materials Have Not Impaired Industry's WAR PROGRAM

Ingenuity in Shifting Equipment, Finding Substitutes and Devising Short Cuts Has Kept Pace With Vastly Increased Demands—Work of Construction Section of OPC an Important Aid to Industry.

So long as American production of war materials was limited to supplying the country's defense requirements and some part of the needs of the nations battling against totalitarianism the provision of materials and the facilities of manufacture offered no great problem. Specific programs of production with limited objectives were being carried out. With few exceptions however, the materials on which the so-called defense industries depended were in ample supply for the requirements of the time and their demands could be met with relatively little interference with the regular output for civilian use.

With Japan's sneak attack on Pearl Harbor however the situation was completely changed. The United States was plunged into the greatest war in history and the rapid spread of this conflict called for the despatch of troops, ships, and planes to all corners of the earth. Goals previously set for the production of war supplies were forgotten and maximum output of all needed materials became the sole objective.

While the system of priorities designed to meet the needs of different branches of industry approximately in the order of their urgency had worked out fairly well in the earlier period when it was a question merely of the promptness with which orders could be filled it proved totally inadequate to cope with conditions arising after the United States entered the war. Demands for all sorts of materials needed for the manufacture of arms and munitions, for the building of ships and planes and tanks and for the construction and equipment of the many new plants required to turn out these materials multiplied to such an extent that it was no longer possible to meet both military and civilian needs in full. Priorities were replaced by allocations, a system under which total available supplies of essential materials were surveyed and assigned to the uses deemed most important. Stocks of these materials were frozen and their use for other than war purposes was forbidden or severely restricted according to the degree of stringency. It was impressed upon industry generally that the utmost economy in the use of these materials was imperative as a contribution to the war effort.

Even in the earlier stages of war preparation it had been found that serious delays in plant construction frequently occurred because of failure to obtain delivery of some particular piece of machinery or some minor part at the time when it was needed. Pressure upon certain lines of manufacture was more severe than upon others. Sometimes the fault lay in the failure of constructors to place orders sufficiently in advance. Many of the equipment fabricators who normally supply the oil industry are now extremely busy on other war work while their competitors still have idle capacity or at least are able to do oil refinery work with a minimum of delay. As an example, one of the largest fabricators of oil refinery

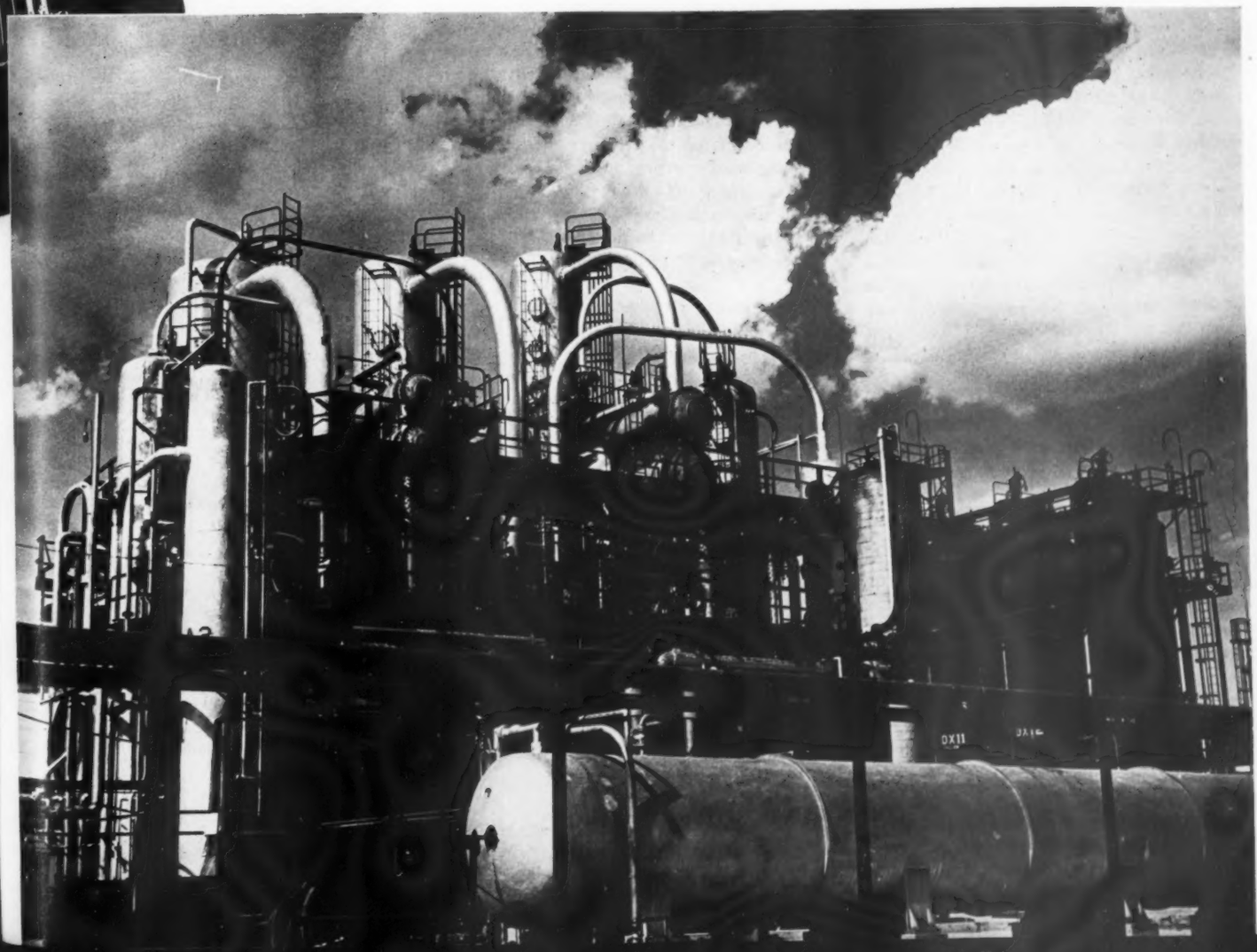
New plants (left) or new units and revamping in existing refinery centers (below) has been going forward with economy in the use of critical materials but in pace with the growing demands from the military establishment.

equipment in normal times, is now almost completely occupied in building special equipment for the synthetic ammonia program. This plant is one of the few which can build the equipment required for synthetic ammonia and must take this work. However, others who are equally well equipped to do oil refinery work do not have the equipment for the ammonia work and therefore can give better deliveries on the refinery equipment.

In the building of refining units to manufacture 100 octane gasoline or other war materials, where a wide range of equipment was required, the possibilities of delay from this cause were particularly numerous. To have a refinery costing some millions of dollars kept from its task of supplying aviation fuel urgently needed by the fighting forces because of failure to receive caps for its towers, a set of valves or a control instrument was a handicap of serious import to the war program. Much valuable time was spent by oil company engineers, builders of plants and government officials in the effort to prevent or straighten out tangles of this sort. It was one of the tasks that the Refining Division of the Office of Petroleum Coordinator undertook soon after its establishment as a joint service to the oil industry and the government. Later on, as the list of critical materials grew longer and the difficulty of obtaining some of them increased, a special Construction Section of the Refining Division was organized under the direction of Max B. Miller, well known to the oil industry as a successful inventor, engineer and builder of plants.

As a result of the work of this Construction Section, together with the energetic efforts of plant builders and oil industry engineers, the program for the expansion of 100 octane gasoline production which was the chief concern of both industry and government has been carried forward on schedule and the production of this essential product has kept ahead of current military demands. Work of the Construction Section involves much more than the name implies. While it follows closely the progress of plant erection and the delivery of materials it studies and suggests ways and means of minimizing the use of scarce materials, suggests short cuts in construction and operation and encourages simplification of design and specifications wherever this can be done without substantial loss in efficiency. It acts as a clearing house for the exchange of ideas that contribute to the saving of time and materials. Its primary purpose is to see that materials for the job are on the job at the time when they are needed but this involves much more than a mere checking up on orders and deliveries.

In submitting plans and estimates for specific projects proposers are required to file lists of ma-



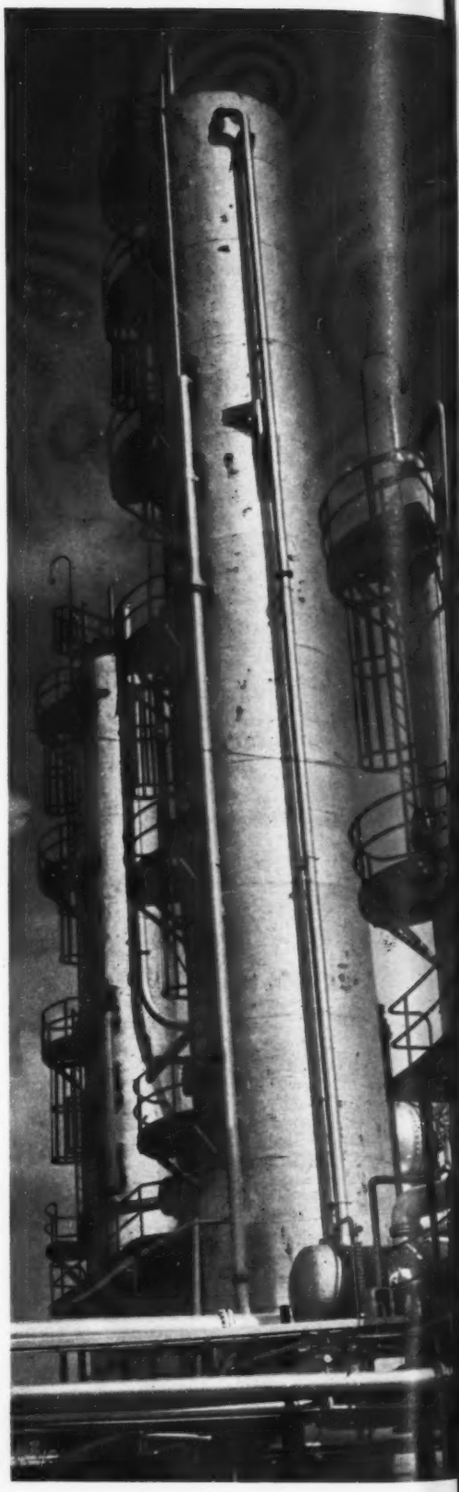
terials needed with required delivery dates. From these lists the Contract Section draws up composite schedules showing the amounts and kinds of materials required for the entire program and also a time schedule showing the dates when these various supplies will be needed. In order to meet the time schedule set up for the completion of a refining unit it is not sufficient to place orders with fabricators for delivery by specified dates of towers and tanks, engines, pumps, valves, pipes and fittings and all the other kinds of equipment involved. The fabricators of this equipment must be able to obtain the steel and other materials entering into its manufacture. The Construction Section of the OPC sees to it they are supplied in this respect and up to date substantially all requests have been filled in accordance with the program.

As is true in most lines of war activity steel is the material most in demand for the construction of refining units. Steel plate is the most critical form. At present rates of delivery 90 per cent of the plate required for the part of the program to be completed before July, 1943 will have been supplied by the end of the year and the peak demand for this purpose will be over unless, as now seems probable, the intensity of land and sea fighting and the leading part in it assigned to high powered planes causes an upward revision in the projected output and the authorization of more plants for this purpose. Not only is steel in large quantities required by the refining industry but much of it has carried high alloys of such critical materials as chrome and nickel. Scarcity of these elements and a desire to lighten the pressure on plants producing high alloy steels has led the War Production Board to work out specifications for what is known as national emergency steel with a lower alloy content than designers have been specifying in the past. In certain refining equipment where high temperatures or corrosive oils must be dealt with, as in furnace parts or plates for towers it is recognized that alloys cannot be dispensed with but experiments have indicated that some economies in their use are possible and wherever possible the use of the milder NE steels is urged even though this may involve some shortening in the life of the equipment. Aside from these general considerations other time and material saving devices are investigated by the Construction Section. In a bulletin distributed earlier in the year it was suggested that strip mill or rolled plate be substituted for scarce sheared plate in units where only normal pressures and temperatures were required and information was provided as to the mills capable of supplying strip rolled plate with the dimensions available. Use of electric welded tubing and butt welded pipe in place of seamless steel tubing urgently required for munitions manufacture and the substitution of other materials for galvanized steel sheets as weatherproofing insulation were other recommendations. Another means of simplifying and speeding up steel mill operations has been a reduction in the variety of specifications for tubing and other equipment. In the past the individual preferences of designers have led to a multiplication of specifications and compliance with these naturally slows down the production capacity of fabricators. Under stress of war necessity it has been possible to reduce these from as many as fifteen or twenty to half a dozen classifications accepted as standard by the entire industry.

While the capacity of American steel mills is so great that in peacetime it is hardly ever fully employed even in periods of greatest industrial expansion the present situation is putting them to a test such as they never have faced before. Steel in huge quantities is required by all the instruments of war and the demands for allied nations under lend lease have risen to a point where the United States has become the chief supplier for all the United Nations. Consequently no other commodity is studied more intensively in the effort to effect savings in its use in construction or to find acceptable substitutes where this is possible. Recently the War Production Board organized an Iron and Steel Division to supervise the use of these commodities and drafted Reese H. Taylor from his post as president of Union Oil Company to act as chief of this division. As the war program has progressed ways and means of curtailing the former liberal use of steel plate and structural steel have been worked out. Rebuilding of old tanks has helped and the Construction Section of OPC has recommended that steel platforms and stairways be reduced to a minimum as a temporary measure. A circular letter sent out by Mr. Taylor directs attention to the substitution of other forms of tubing for the cold drawn seamless type. In every possible way it is being impressed upon the users of steel that every pound saved in construction means an additional pound for the making of shells or tanks or ships. The engineers of the refining industry are responding by discovering hundreds of large and small economies and substitutes. One such is the use of transite or plasticized materials in place of sheet steel for roofing, side walls or the weatherproofing of insulation.

Provision of power equipment has been the cause of many headaches, particularly in types that are used extensively in shipbuilding. Steam turbines, gas and Diesel engines, have been in short supply and plant constructors have been urged to make use of electric power, reciprocating engines and gasoline engines of the automotive type wherever possible. Compressors, reduction gears, centrifugal pumps, valves, fittings and instruments have presented bottlenecks of varying degrees of severity. To relieve this situation so far as can be done orders have been spread among as many manufacturers as possible, hookups of smaller sized units have been arranged in place of larger sizes difficult to obtain, direct or belt drive has been substituted for gears.

One of the devices to which plant engineers have resorted in order to obtain equipment urgently needed for war production has been the "borrow-



Older plants are undergoing extensive revision occasioned by the shift in demand for refinery products: butadiene and toluene hardly needed to be taken into account when the refineries shown above and to the right were constructed; aviation gasoline was a minor consideration. But by the exercise of great ingenuity the industry has been able to convert much of its existing plant to produce the new products demanded by war conditions.

ing" of parts from plants where full production is less essential. This has extended to the virtual dismantling of some plants not so equipped or located as to be readily convertible to war work but which are not urgently needed for commercial products owing to the decrease in commercial distribution of certain petroleum products.

Not all the equipment made available for use in war plants has had to be taken from active duty elsewhere. A helpful source of supply has been the reserve of spare parts carried by the majority of plants. It frequently happens also that a piece of machinery in good condition that has been displaced in the course of reconstruction that is always under way in a large refinery is allowed to remain in the plant or yard even though there is little likelihood of its being put to further use. An example of the way in which such equipment can be brought into service was afforded some weeks ago when additional compressors were needed. The Construction Section asked the various oil companies to supply information as to any compressors that they might be able to spare. As a result, compressors aggregating 92,000 horsepower were reported and a large number of them were placed in plants where the need for such equipment was urgent. Profiting by this experience the Section has asked for similar listings of other spare equipment and materials which can be made available.

Inquiry sometimes reveals the existence of manufacturing capacity that is not fully employed. This happened recently when the Construction Section, made apprehensive by the apparent tightness in the supply of valves, sent out a communication on the subject which uncovered the fact that certain makers of this equipment were in a position to handle additional orders which were promptly placed. Nevertheless the Construction Section believes that a shortage in this line of equipment as to certain types and sizes is likely to develop and has recommended that orders be placed early instead of following the practice which it declares is rather common of leaving this equipment until among the last to be purchased for a new or reconstructed plant.

Demand for usable second hand equipment long since outran supply but in the reconstruction or enlargement of units it sometimes happens that certain equipment can be discarded and this is immediately snapped up for use in other projects. Officials of one large refining company recently reported to the Construction Section that a rearrangement of their tankage equipment would enable them to eliminate three floating roof tanks of 140,000 bbl. capacity each which were in process of construction and these were immediately assigned to another project in need of this particular equipment. Another refiner removed a set of tanks from one location to another and equipped them with new roofs although the expense of this operation was greater than the cost of new tanks of equal capacity. The company cheerfully assumed the loss involved in this procedure because of the substantial saving in steel for the war effort. The devices to which oil industry engineers have resorted to find ways of saving critical materials, shifting equipment and replacing machinery difficult to obtain without sacrifice of efficiency would fill a volume. They constitute a tribute to the ingenuity of the men handling these practical problems as well as to their whole hearted zeal in putting the war program through to a successful issue.

Research investigations that were put under way long before the war started are bearing useful fruit in meeting the new conditions that have arisen. Recently Standard Oil Company of Ohio informed the chief of the Construction Section that it had been experimenting for a year and a half with enamel bubble caps on the vapor inlet trays of primary towers and that several hundred of these had been in use for a year or more with entirely satisfactory results. Inasmuch as chrome has been extensively used in the making of bubble caps because of its ability to resist corrosion the substitution suggested points to a potential saving in a war-scarce material and tests are being made to determine whether other extensions in its use may be adopted.

Labor, space and time saving ideas have contributed to the effective conduct of wartime operations in the refining field. A suggestion along this line advanced by Sinclair Refining Company as a result of its own experience has proved its practical usefulness. This provides for the construction of towers in sections, each ring with its bubble trays and internal connections being completely fabricated, stress relieved and shipped to the point of erection where the various parts are put together and welded. The advantages of the system include a great increase in shop capacity, the utilization of steel as fast as received, greater facility in transportation and easier handling in the field where the plant is to be erected.

These few examples are but a slight indication of the many ways in which the engineering and operating forces of the oil industry are working to devise new methods, to save scarce materials and to find short cuts that help to keep the war construction program moving on schedule or in many instances ahead of schedule. The Construction Section of the Office of Petroleum Coordinator performs an important function in this movement by providing for a steady flow of materials to the point where they are needed, by originating practical suggestions for time and material savings and by acting as a clearing house for ideas developed out of the experience of individuals and companies and making these available to the industry at large. The whole undertaking typifies the kind of team work that is being applied to the entire war program of the refining industry and that is enabling it to meet the vastly increased demands imposed by the swift extension of the world conflict.

THERMAL CRACKING Facilities Can Aid Nation's War Effort

Conversion of Existing Plants Offers Quick and Economical Means of Providing Additional Aviation Fuel, and Rubber Intermediates

By Dr. M. B. Cooke

IN A PAPER published in this magazine* in October 1939, just after the start of World War II, it was predicted that the defense of the United States would call for many more planes and the fuel to feed them, that European countries no doubt would call upon the United States for large quantities of high octane fuel and that the production of aromatics from petroleum would assume a new importance, particularly in the production of toluol and benzol by catalytic cracking and thermal polymerization. These forecasts have proved to be far short of actual developments, for the present military requirements of the United States itself and the demands of the United Nations for aviation fuel call for the installation of such processes on a scale that taxes the national capacity for the production of alloy steels and other critical materials needed for their essential plants.

In view of the fact that almost three years have passed since the article referred to was published, it may be worth while to look back and see what has been left behind, and what has been picked up en route to the Land of Synthetic War Materials, with particular attention to the two materials that have come to occupy a chief strategic position in the American war program, that is to say, aviation gasoline and rubber. Had it been possible to foresee the world conflagration in its present dimensions and to plan our production program on the basis of the total involvement in which we now find ourselves, we could have been further along the road to maximum output on which we are now racing in desperate haste. Had America been thinking in terms of war and the ability to overcome powerful foes we would have busied ourselves in studying the arts of destruction and would have directed our industries to forging its instruments on a vastly effective scale. As we all know, however, Americans have not been thinking of war and almost until the moment when it was thrust upon them they were unwilling to believe that it could involve them directly. Consequently the growth of American war production has not been that of a carefully planned edifice but has proceeded piecemeal with additions here and there as the unfolding of events forced them upon us.

First steps toward the development of military strength and of the materials needed to make that strength effective were taken as a measure of defense against a possible attack that to most persons seemed decidedly remote. The second phase opened when we undertook to become the "arsenal of Democracy" and to supply the nations fighting against totalitarianism with the tools of war. Among the petroleum products most in demand by these nations was aviation fuel and it was then that the expansion of 100 octane gasoline production was put under way on a substantial scale. Even in the middle of 1940 the provision made for synthetic rubber production was relatively insignificant. Not until after Japan's back-stabbing assault did the urgency of large-scale production of butadiene impress itself upon official Washington. It was still later before the full extent and importance of the need for various aromatics was realized. Thus the construction program for 100 octane gasoline production was handled as a separate undertaking with authorization of a larger number of installations to be devoted to this specific function, while the problem of synthetic rubber came in for later attention and was treated similarly by projecting another series of costly plants for the production of butadiene. The provision of toluene and other specialized products that have been found to be required in vastly greater quantities than originally anticipated has been treated in much the same manner. It is questionable whether there is, or will be during the course of the war, enough of the necessary materials to provide for two or three sets of plants. Logically, the synthetic rubber program should be tied in with the aviation fuel program and the provision of petroleum war products should be dealt with as a single problem. That this was not done from the beginning was due in part to the way in which the war effort as a whole has moved through successive stages as described above. On the part of the oil companies who presented proposals for the erection of plants there undoubtedly was a natural disposition to plan their new construction with regard to its long term usefulness rather than as emergency undertakings for purely war purposes. The whole training and tendency of oil industry and construction engineers has been to use the best materials, even to use them lavishly, and to build plants that would justify their existence on the basis of commercial operation. The time has come, however, when further expansion of petroleum war production must utilize the quickest and most economical (in materials) methods of meeting mounting requirements, regardless of the effect on the future efficiency of plants or their ability to maintain a competitive position in industrial operation after the war. In other words, production for war use no longer can be treated as an undertaking subordinate to the ordinary commercial operations of the industry. "All-out war" is more than a phrase today. We are in the midst of it, and it calls for the utilization of all national resources to the fullest possible extent. In the oil industry there are still undeveloped possibilities in this direction which can be developed without undue drain upon strategic materials, which will permit a broader participation in the war program by independent refiners and will provide continuous activity for plants which otherwise might be forced to suspend operation because of shrinking domestic demand for their products.

While American petroleum technologists have made great strides during the past two decades in the improvement of products, particularly in the field of high octane fuels, and while oil companies and equipment manufacturers have been active in the installation and operation of the latest processes and plants in foreign fields, one thing of importance was somewhat neglected. They did not appreciate, or at least did not sufficiently impress upon their chiefs and their own government, the significance of European developments. An example in the field of aviation gasoline is the use of aromatics. In the early thirties an active debate was carried on among oil experts and engine builders on this subject, particularly in connection with the use of aromatics in air-cooled motors. Back in 1934 the debate became so hot that a test was finally run in an airplane under various flight conditions. As a result of this test the use of aromatics in aviation gasoline was banned because the heads of the air-cooled motors ran some 25 degrees Fahrenheit hotter than the same motors showed when operated on fuels of low or no aromatic content. Specifications of the government and of airplane motor manufacturers thereafter rejected a fuel if it contained as much as one percent of aromatics. The question of gum deposition also was brought up as an argument against aromatics although the solution of the gum problem offered no great difficulty. The use of aromatics was dismissed in this country but elsewhere the study of their potentialities continued, and the writer was informed by a member of the British Air Ministry in 1937 that squadrons of light bombers were flying about in England with fuels containing up to 30 percent by volume of benzol and other aromatics in their tanks. This information was brought to the attention of the American government and an offer was made to bring over a twin row radial motor for testing purposes. No action was taken then or in 1939, when the offer was repeated. It was left for actual war experience to demonstrate that the use of aromatics in aviation fuel is a "must" and no longer optional. The so-called rich mixture characteristics of aviation gasoline are enormously enhanced by the presence of aromatics. The dive bomber using such fuel will come out of his dive and leave his

* "Demand for Aviation Fuel Coincides with Era of Catalytic Cracking" by Dr. M. B. Cooke, World Petroleum, October, 1939.

The first commercial Gyro vapor phase thermal cracking unit: refineries of this type could be readily converted to production of butadiene for the synthetic rubber industry.

opponent operating with paraffinic fuels such as alkylate and catalytically cracked blend stock far behind—or on the ground.

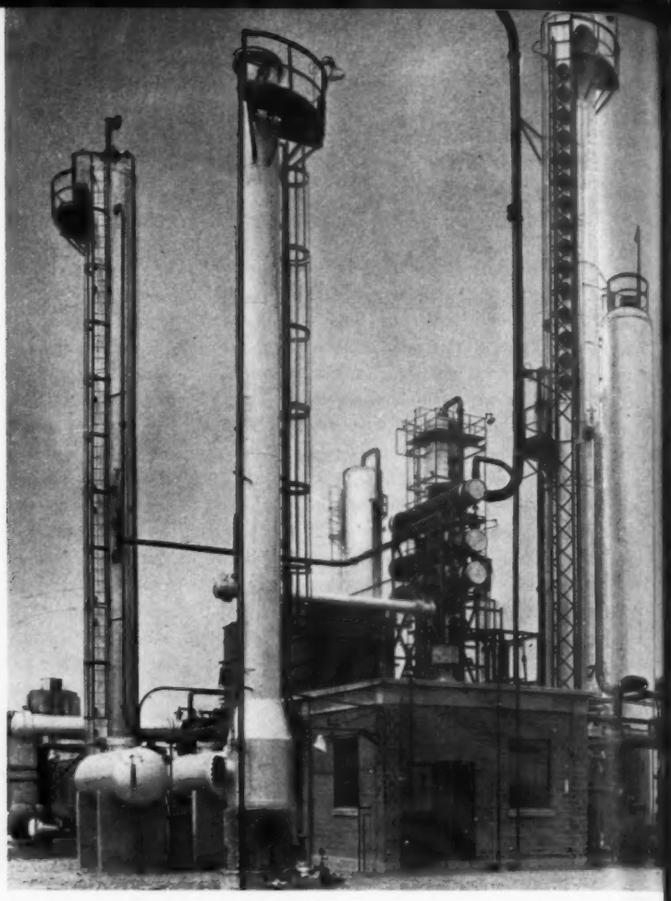
With emphasis placed, and rightly so, upon mounting requirements for large volume production of aromatics, it is to be noted that catalytic processes yield only small amounts of aromatics unless the plant is especially designed for their production, such as the Hydroforming process. To provide quickly the supplies of the special products that apparently will be required in increasing quantities, a way out is afforded by recourse to existing thermal cracking plants which can be converted to this purpose in much less time and with much less consumption of critical materials than is involved in the construction of new and costly plants. The existing cracking capacity of this country amounts to about 3,000,000 bbl. per day of crude oil. If proposed rationing plans for the domestic use of motor fuel are carried out, half this capacity will be sufficient to serve civilian requirements. The other half can be made available to meet the need for rubber intermediates and aromatics.

The conversion of existing plants for the production of aviation aromatics, butadiene and butylene, as well as styrene and the necessary ingredients of our present alkylate and iso-octane, can be fully accomplished in about six to eight months. This compares with the eighteen to twenty-one months for projected catalytic plants. The method of conversion would call for the lowering of the pressure of operation in the case of the majority of the plants to about 15 pounds per square inch, as compared with their present operating pressure of 350-700 pounds. The throughput would be somewhat reduced, but due to the fact that naphtha is one of the best raw materials for the contemplated operation it is assumed that the units, after conversion, would be comparable to vapor reformers more than to ordinary heavy oil cracking units. It is known that a cracking unit will usually reform an amount of naphtha equal to the volume of heavy oil charged per day, because the amount of oil going through the coils is only the raw stock and not recycle. There are several possibilities in the conversion scheme which have to be studied for each individual unit, but the plants are all so nearly the same in regard to the fundamentals involved in the heat-time factor that it is easy to make up a schedule for the whole industry and vary only the details. The cracking units are all capable of being converted to vapor phase, and it then becomes a question of minor changes in the particular unit under study.

Owing to the scarcity of materials required and difficulties in construction it is a safe assumption that the country will not obtain all the rubber it needs by the time it will be needed through the erection of costly specialized catalytic cracking plants. To fill the breach and to produce the needed raw materials, butadiene, butylene and styrene, as well as aviation gasoline, advantage will need to be taken of thermal plants and processes. The most practical way to do this is to turn to the program suggested by the writer as a representative of the Gyro Company, in January, 1942, which involves the reconstruction of a hundred or so of the thermal plants which are or will become idle because of a lack of tires and gasoline for private travel.

The conversion of existing cracking plants for the alleviation of the acute need for both aviation gasoline and rubber involves the fundamentals listed: (1) The high pressure units (which are over 90 percent of the total available) must have their operating pressures reduced to about 15 pounds gage. (2) They will have to operate on clean vaporizable stock. (3) The fractionating towers are the limiting factor in capacity in vapor phase operation because the volume of gases to be handled is increased in two ways (a) lowered pressure of operation and (b) the higher temperatures employed give rise to greatly increased gas production. (4) In the vapor phase operation there is the problem of charge stock preparation —either the oil to be cracked must be vaporized and flashed free from residual oil, or there must be furnished a vaporizable charge stock such as naphtha. The latter is the preferable stock for these high temperature operations, for long runs can be made and the yield of the butadiene and butylenes are a maximum. The latter can be used for both purposes, aviation and rubber. There is obtained a high yield of aromatics when operating on light stocks (if desired) or a composition which lends itself to immediate and simple extraction. (5) The problem of extraction of the butylenes is a simple one, usually involving an azeotropic distillation. The Union Oil Com-

Experimental Gyro unit in lower foreground: installed in 1932 in connection with a complete semi-commercial distillation unit.



A recently completed True Vapor Phase unit now in commercial operation: limited quantities of scarce alloy steels are required to revamp plants such as these for production of butadiene.

pany of California has such a process, as does the Phillips Petroleum Company of Bartlesville, Okla. These processes are perfected, and are ready to go. The butadiene is obtained in a high yield (recovery) and the aromatics extracted have been passed on as suitable for all uses to which aromatics are put in the chemical industry.

The two best known thermal liquid phase cracking units were probably the Cross and the Dubbs (later U. O. P. Co.). These units were and are identified by their operating pressures of 350-700 pounds and their phase (in each case believed to be substantially liquid). The furnaces are equipped, in most cases, with carbon steel tubes which were and are satisfactory for operating temperatures not exceeding 950-1000° F. In the change-over to vapor phase, 1100-1400° F. operation it is only necessary to remove some of the tubes in the high temperature section of the furnace. These tubes must be replaced by alloy tubes, the composition of which varies but may be classed as "chrome tubes" in general. A tube known to have the proper life is made of 5 percent chrome, ½ percent molybdenum and 1½ percent silicon. This tube shows good oxidation resistence up to 1500° F. and fair creep strength up to 1300° F. Another manufacturer put out one called Sichromo No. 3, which is good for at least 1300° F. It is only necessary to place these tubes in the furnace when the oil vapors pass 1000° F. and eventually reach 1350-1400° F. in case of the high temperature-maximum yield of butadiene type units, and those units where aromatics are desired. The latter require a time formation much greater than the butadiene. If the old furnace tube hangers are of alloy steel, it probably is not necessary to replace such hangers.

The transfer line from the furnace to the quench point must be of alloy steel to withstand the high temperatures of 1200-1400° F. Particular attention should be paid to air hardening of the alloy transfer line for it may become dangerously brittle in service. After quenching, the temperature having been reduced to at least 600° F., the mixture is passed to a fractionating tower or it may be quenched down with water to 100° F. and the gases removed from the liquids. Existing plant equipment will decide which system is preferable. If the vapors are fractionated the fixed gases leaving the tower under 10-50 pounds pressure are compressed and scrubbed clear of condensable hydrocarbons by an absorption system. The condensate is stabilized in order to collect the most desired cuts of C_4 and aromatics in separate fractions. The former is contacted with special solvents for segregation of butadiene and isobutylene, the two chief rubber raw materials. The olefins and paraffins not wanted are recycled.

The aromatic distillate is cut to fractions: one containing benzol and the other toluol. These are selectively removed by special solvents, washed with acid and redistilled. The usual "bottleneck" in most proposed conversion units is the fractionating tower. This can be overcome in most cases by installing a cheap, second-hand, reworked, large-sized bubble tower with 10-12 trays (or a packed tower) to give reasonable separation of distillate from residue. The operating pressure will be less than 50 pounds and this makes second-hand towers fit the requirements. The services of the existing depropanizers, debutanizers, bubble towers, and the like can be switched around so that enough equipment is on hand at any first rate refining (liquid phase) unit to do the job. It is to be assumed, of course, that compressors will be necessary. Outside of chrome tubes and compressors, it is not believed any strategic war materials will be needed.

The systems of Gyro, True Vapor Phase, and Cooke are adaptable to the present problem of diolefine and olefine production without change. They can be used as they are, for they have already been used, and have produced the only butadiene and aromatics in quantity which have been produced in this country with the exception of that produced by the expensive and complicated catalytic hydroforming process. The latter plant was built specifically for the production of toluol, and so far as is known is doing what it was designed to do. There is no criticism of the ability of engineers to design and build catalytic plants for specific jobs; that can be done and has been done to the great national benefit. The criticism is, in the present case, that there is not enough alloy steel and other critical material in the country for the immediate construction of giant catalytic plants to produce the huge quan-

tities of butadiene and the butylenes and the aromatics demanded this year and next, not in the year 1950 or 1955. This fact is certain; if a catalytic unit can be constructed with no limit on the amount of material of construction and no consideration given to yield of the desired material of output they are capable of turning out a fine product. If time is of the essence, then the picture is one of absolute clarity; it will show that the conversion of existing thousands of tons of steel and the millions of parts which go to make up a modern thermal cracking plant is a sensible, quick way in which to produce the needed materials of rubber and aviation gasoline.

In converting the existing thermal plants to vapor phase cracking units it is first necessary to plan either to use the existing fractionating equipment as-is (this gives the most rapid conversion plants after-the-war-value), or to plan on adding to the fractionating equipment. The problem is one of vapor load on the fractionating towers and the cooling and condensing capacity of the existing equipment. Since most thermal cracking units use a recycle ratio about 3-1 or 4-1, it then is not a question of heating capacity of the furnaces, for the vapor phase cracking here contemplated calls for once-thru operations with either no recycle, or at least with a small ratio of recycle in the range of 1-1 or 2-1. The furnaces in most cases can be rebuilt to have part of their present heating coils divided into a vaporizing section and into a high temperature cracking section. The vaporizing of light stocks, such as naphtha, is comparatively easy and the cracking of this stock at 1350-1400° F. is accomplished easily if there is available a comparatively small number of alloy steel tubes to withstand the high temperatures. The time factor is very short in the production of butadiene, being in the hundreths of a second and not in the range of minutes, as it is in thermal-high-pressure cracking for ordinary gasoline. For this reason it is not necessary to have any soaking bank of tubes at all—in fact it is fatal for yields if a long time-factor is used in the production of butadiene. If it is desired to produce a high yield of aromatics by the operation, then a soaking is necessary, but in this case it is usually necessary to withhold all heat input into this coil, or even to cool the coil externally. The formation of aromatics by polymerization is highly exothermic, as demonstrated on commercial Gyro-Pure Oil units built and operated several years ago. The formation of the maximum yields of butadiene calls for high temperature and extremely short time. The formation of high yields of aromatics calls for the same temperatures, but the time must be lengthened considerably.

In commercial operations for the thermal production of butadiene we usually find that we obtain a happy medium as the final result, viz: the plant will turn out butadiene to the extent of 4 to 7 weight percent of butadiene from naphtha cracking, and at the same time it will produce some 10 weight percent of aromatic (purified basis, so that the aromatics are suitable for nitration). This type of operation is the easiest to plan for in the conversion type of thermal unit, inasmuch as the units will not be adaptable to give the maximum yield of butadiene—10 weight percent—unless they are equipped with gas heating medium steam or super-heated steam from an external source. The latter is not recommended, since our country needs boilers as well as rubber, and this would call for a very large boiler capacity. If heated gas is used to cut down the time and raise the yields of butadiene according to the patents of TVP or of Cooke, it will lengthen the time of converting the units. The maximum speed of converting the existing thermal cracking units calls for using the units as they are, as closely as possible. They should only be changed as little as possible, so that time will be saved as well as critical and strategic materials. The maximum yield of butadiene does not have to be attained in this case, as it is an emergency matter, and if the time is relatively long another needed material for war will be obtained in increasing quantities, aromatics. The yield of butylenes is increased when the yield of butadiene is relatively low. The production of butyl rubber is, it is believed, as important as the production of Buna S, and this balances out the defect of reduced yield of butadiene.

As an example of the two types of operation there is shown in the following table the results of thermal operations by two methods of operating a thermal cracking unit:

	High Temperature—Short Time	***High Temperature—Long Time***
(With Gas or Steam)		
Charge Stock		
Yields	**225-400° Naptha**	**Characterization Factor 12.0**
Butadiene	**10.0 wt.%**	**6.0 wt.%**
Butylenes	**14.0**	**18.0**
Aromatics (pure)	**2.0**	**11.0**
If we include other war gases obtained, we show the following		
Propylenes	**9.0**	**19.0**
Ethylene	**23.0**	**21.0**
Total	**58.0 wt.%**	**75.0 wt.%**

It will be noted that the sum of the two major rubber intermediates is exactly the same; 24.0 wt. percent. The yields of aromatics are radically different, as are the yields of propylene, while the yield of ethylene is not materially affected. It would appear from these data that the correct method would be the second, involving a reasonable yield of butadiene and a high yield of aromatics, since the amount of rubber resulting from the operation would be the same, and this then throws the economics toward producing the other direly needed raw material, aromatics. It will be noted also that the yield of propylene is high in the second case and this is conducive to high yields of isopropyl benzene, if the benzene is united with propylene.

Gyro units were operated on reduced crude and it was found that butadiene is formed in considerable quantity even in normal Gyro Cracking operations. One such commercial unit was operated in the Mid-Continent field for a year or so, and the butadiene was extracted by one of the regular extraction methods. As a result of this operation the C_4 cut amounted to 12.0 wt. percent of the total gas, and the percentage of butadiene in this cut was 14.5 percent.

The isobutylene amounted to 40 percent, and the normal butylene was 20 percent.

Based back on the charge this amounts to:

Butadiene	12/	14.5%—1.74% on charge
Isobutylene	18/	12%—2.16%
Normal Butylene	6/	12%—0.72%

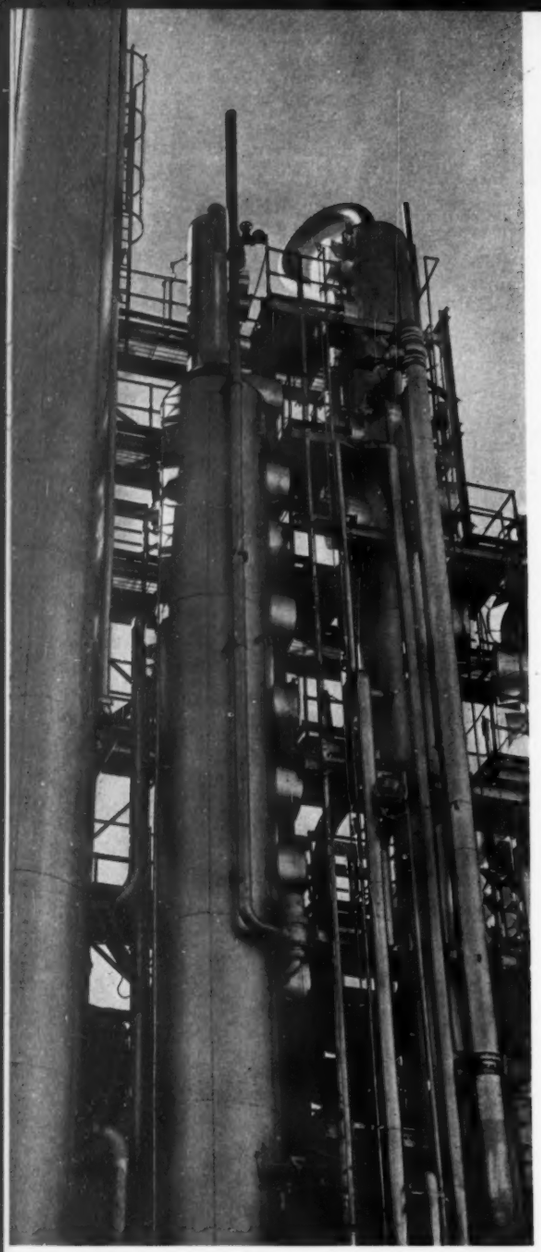
If the same units are operated on naphtha as the charge, instead of on reduced crude oil charge, and at maximum temperature, the yields become

Butadiene (C_4 fraction amounts to 14.0% by wt.)	30.0/	14.0%— 4.2 wt. % on charge
Butylenes	14.0/	60.0%— 8.4%
Aromatics (pure)	11.0 wt. %—11.0%	
Propylene		9.0 wt. %
Total useful products		32.6 wt. %
The ethylene amounts to		14.0%
		46.6 wt. %

The above figures are the maximum attainable at present and involve major changes in the units. The use of temperatures as high as 1400 degrees F. is contemplated, and this calls for the best obtainable chrome steel tubes to withstand the high temperatures. This conversion is not as quick as would be raising the temperature on existing Gyro or TVP units, or by a moderate conversion of existing thermal high pressure units such as the Kellogg-Cross, Tube and Tank, Winkler Koch, and Dubbs.

As an example of the possibilities of the conversion of thermal high pressure units in this country to produce the emergency materials, butadiene, butylene, and aromatics, the following approximations are believed to be reasonably correct.

(Continued on page 88)



RECENT DEVELOPMENTS

WHEN the present war is over and historians review our state of preparedness to assume the burdens of war when the Japs struck on December 7, 1941, it will be evident that our petroleum industry was well prepared to meet the needs of a modern war machine for lubricating oils as regards both quantity and quality.

Fortunately, research on the development of superior lubricants for high output internal combustion engines has been prosecuted intensely since about 1928, and the results obtained were so outstanding that the translation of the new refining processes and compounding formulae into commercial use followed close on the heels of the research. Consequently, when we were thrown into war, not only did our technologists know how to make the superior lubricating oils to be needed in an all-out war effort but the facilities for producing such lubricants in probably ample quantities were already in operation or under construction. In the following review, it will be apparent that production of the most valuable lubricants for severe service conditions consists of two distinctly different operations; namely, (1) the production of a well refined hydrocarbon oil containing a minimum of hydrocarbons of undesirable types in view of the intended service and (2) the addition of chemicals or compounds to improve further the efficiency of the oil for the specific service intended. As will be seen, the development of these two phases of modern lubricating oil production took place one after the other and in the order mentioned.

Before about 1928, lubricating oil refining was principally for color, flash point, cold test, and carbon residue, although the importance of sludging and general oil deterioration with engine use had become fairly well recognized. The refining processes available, however, were so limited in their application and effectiveness that the inherent nature of the crude oil at hand was the controlling factor as regards the composition and properties of the finished lubricating oil. Therefore, it was only natural that up to that time, it had been customary to think of lubricating oil quality in terms of crude source. In fact, so well founded and widely accepted was this method of designating quality that even today after such designations have become practically meaningless because of modern refining and compounding practices, one still finds occasionally crude source being taken as the basis for evaluating quality. Indeed, it was largely the desire to reproduce exactly the physical properties of "Pennsylvania" lubricating oils which inspired and supported much of the pioneer work on certain solvent extraction and dewaxing processes which have now become in lubricating oil production as indispensable as cracking in gasoline production. Since oils were sold in the earlier days principally on the basis of physical specifications, such as gravity, flash and fire, viscosity-temperature slope, color and carbon residue, the first objective was to meet the required specifications for these physical properties. The research chemist, however, felt that the surest way to duplicate not only the physical but also the chemical properties of oils found best in service was to duplicate these oils from a chemical point of view. Consequently, it was undertaken to devise methods which would permit the crude lubricating oil stock to be separated or fractionated on the basis of chemical composition into as many fractions or component groups as desired. This would immediately permit the refiner to select the appropriate fractions required to duplicate any other sample of hydrocarbon lubricating oil, thereby removing forever the limitations or preferences imposed by crude source. The practical answer to this problem was found in efficient, economical solvent extraction and dewaxing processes now in everyday use.

On account of the fact that California crudes give unrefined lubricant stocks farthest away from "Pennsylvania" oils, the need for drastic refining methods was perhaps felt strongest in California. At any rate, many of the new lubricating oil refining processes were developed on California crudes. The application of these and similar processes to Mid-continent crudes was readily accomplished because these crudes presented less difficulties. Further, it was recognized that many of the solvent treated oils were freer of easily oxidized, unstable, carbon and sludge forming, low V.I. fractions than average "Pennsylvania" oil. To match these new standards of purity, a number of solvent extraction plants have been constructed to operate on "Pennsylvania" oils. Thus, by the fall of 1941, the new type lubricating oil plants were in operation all across the United States, producing lubricating oils from a wide variety of crudes to meet practically any desired specifications.

These solvent extraction processes for separating the lubricating stock into two or more different fractions are not to be confused with fractionation by distillation. The latter process separates the oil on a boiling point or molecular weight basis, whereas, the solvent extraction process is designed to make a separation on a basis of chemical composition. It so happens that hydrocarbons differing in chemical structure but having the same boiling point or molecular weight generally have different affinities or compatibilities with certain solvents. By using a solvent which exhibits a wide difference in mutual affinity or solvent power with respect to aromatic, naphthenic and paraffinic oils, a selective separation is easily made with reasonable efficiency on any cut from a preceding distillation. It is to be noted that solvent treatment and vacuum distillation should supplement rather than replace each other in lubricating oil refining. The undesirable constituents in lubricating stocks consist of asphalt, wax, unstable (low API gravity) oil fractions, and hydrocarbons of too high or too low boiling range. Modern lubricating oil refining, therefore, consists of deasphalting, de-waxing, chemical fractionation (solvent extraction) and boiling point fractionation (vacuum distillation).

Deasphalting is accomplished by (1) vacuum distillation, (2) acid treatment, or (3) propane extraction. Vacuum distillation is used mostly where the asphalt content is high, whereas direct acid treatment is limited to low asphalt contents. Propane deasphalting is applicable to all classes of residue regardless of asphalt content and permits the maximum recovery of paraffinic oil. The

In Lubricating Oils Are Valuable to War Effort

By Ulric B. Bray

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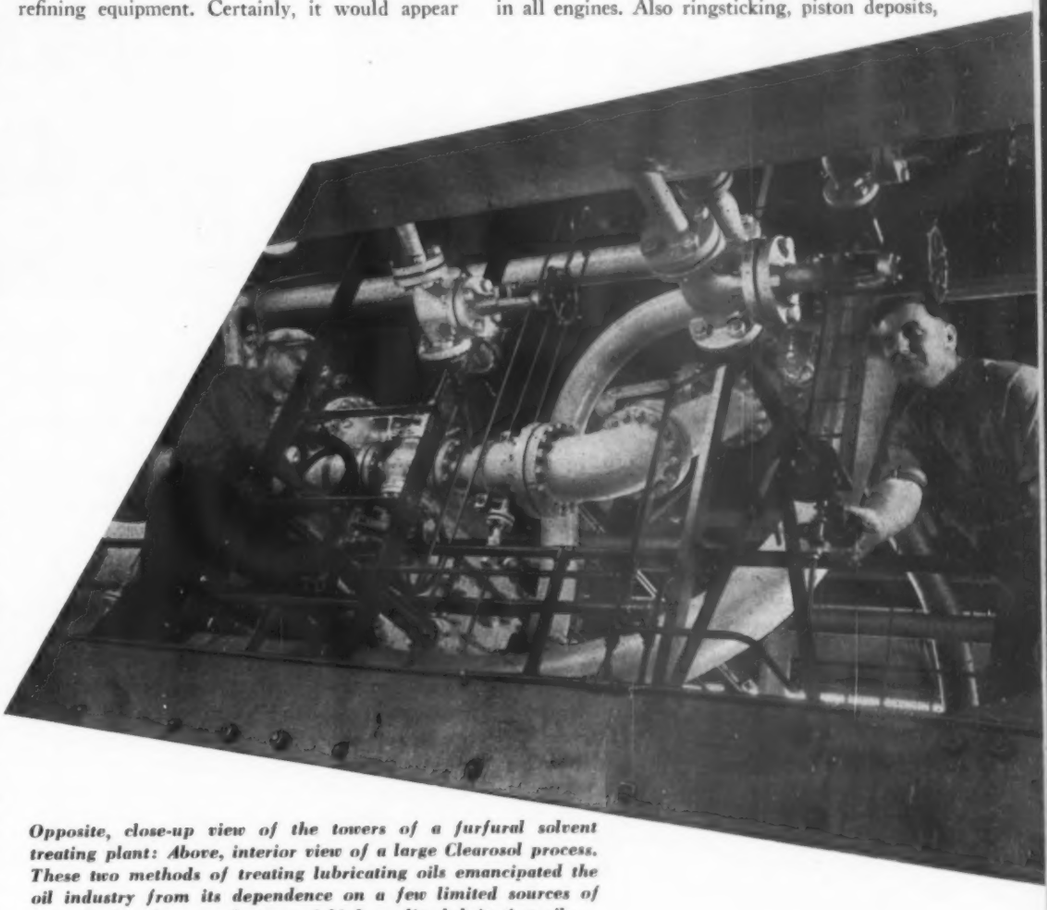
newer dewaxing process which contributes toward the practicability of producing superior lubricants from a wide variety of crudes all employ special solvents and special filters or centrifuges. The special solvents now in greatest use commercially are (1) propane, which serves also as an internal refrigerant as well as a diluent and wax precipitant at low temperatures, (2) ethylene trichloride, which is used with a centrifuge because the wax is lighter than the oil-solvent solution, and (3) a mixed ketone-aromatic solvent such as acetone-benzene, methylethylketone-benzene, or toluene, etc. The older methods of cold-pressing neutrals and cold-settling or centrifuging residual stocks are still employed in many refineries because of installations made before the development of the foregoing solvent dewaxing processes.

Solvent extraction is widely carried out in propane solution using a solvent consisting of cresol-phenol. The asphalt rejected by the propane may be removed as a separate product or may be allowed to collect in the solvent phase along with the aromatic-naphthenic oil fractions. On account of the fact that propane exerts a rejecting effect on aromatic, naphthenic hydrocarbons and to some extent the highest molecular weight paraffinic hydrocarbons, whereas cresol-phenol has a strong solvent power for these materials, this combined pushing and pulling action gives remarkably better results than if the propane is removed before the solvent is applied. This process is producing some of the most highly regarded brands of oil. Where deasphalting by vacuum distillation, propane extraction or acid treatment precedes selective solvent extraction, a single solvent can be used effectively, especially where the stock is of relatively narrow boiling range. Such solvents in commercial use in this country are phenol, furfural, nitrobenzene, sulfur dioxide and dichlorodiethyl ether; of which phenol and furfural are most widely used. Phenol, furfural and nitrobenzene are all capable of producing raffinate of practically any desired quality from a given stock, but the relationship between yield obtained and solvent ratio required to produce a specified quality raffinate will vary somewhat between the three solvents.

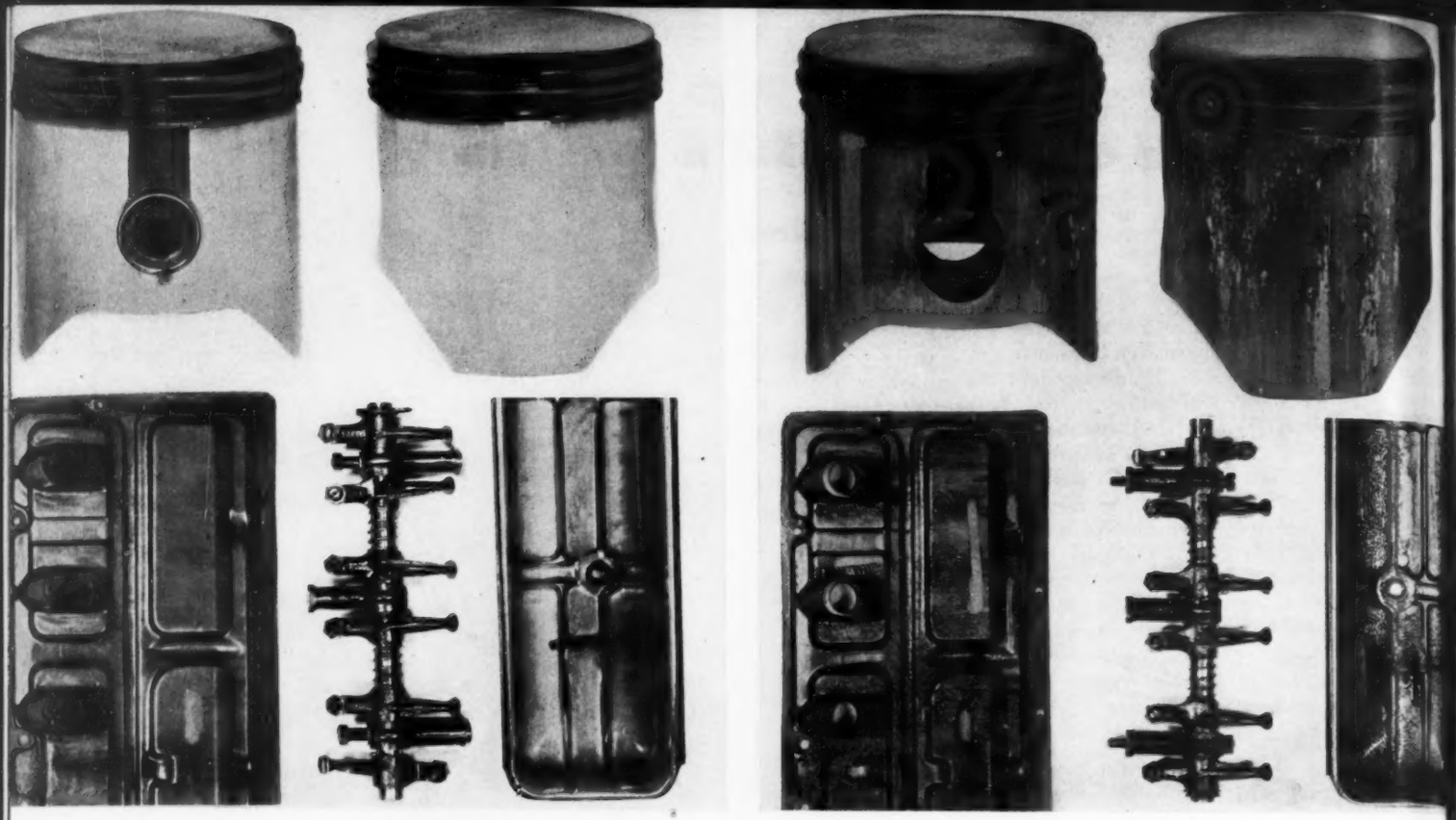
Sulphur dioxide was the first solvent to be used commercially to improve lubricating oils. It is extremely efficient in moving the lowest API gravity components, but where fractions of intermediate gravity must be removed to produce a raffinate of specified quality, excessive amounts of sulphur dioxide are required. This limited range of usefulness and high plant cost have practically restricted the use of sulfur dioxide to naphthenic type lubricating oils and non-viscous oils. While it is neither desirable nor easily possible to give exact figures, it is commonly known that the refining capacity in existence in this country on December 7, 1941, for producing high quality hydrocarbon lubricating oils was very large. In fact, the opinion had been expressed many times during the previous several years that the oil industry had overbuilt its needs for lubricating oil refining equipment. Certainly, it would appear that there is now either built or under construction ample capacity for producing the lubricating oils required for our war effort. For civilian use, the poorer grade oils produced by other methods and equipment should prove adequate both as to quality and quantity for the duration.

In developing the new refining processes reviewed above, it had been hoped that the oils produced by these new methods would permit the solution of practically all lubrication problems. The new oils did show outstanding improvements in many respects, particularly as regards oxidation stability and carbon formation which resulted in cleaner and better operating engines in most cases. However, it soon became apparent that there was room for further improvements, especially in engines designed to give extremely high peak power outputs and to operate continuously at comparatively high power outputs.

With the best of the new oils wear still occurred in all engines. Also ringsticking, piston deposits, galling or scratching of rings and liners, oil ring plugging, bearing corrosion, etc., limited seriously the useful operating time between major overhauls in Diesel and high output gasoline engines. After the confusion following the first blush of disappointment, some of the technologists who had been most active in developing the solvent treating processes quickly diverted their attention to the use of additives while the few investigators who had been pioneering the use of additives in lubricating oil for a number of years, redoubled their efforts in this comparatively unexplored field. The need for something better than the best straight mineral oil was most apparent in high output aircraft engines and in the efficient



Opposite, close-up view of the towers of a furfural solvent treating plant: Above, interior view of a large Clearosol process. These two methods of treating lubricating oils emancipated the oil industry from its dependence on a few limited sources of crude for the manufacture of high quality lubricating oils.



Examination of pistons and engine parts from a small truck that was tested under identical conditions showing the excellent results achieved with compounded Diesel engine oil on the left and the highly unsatisfactory results obtained with straight mineral oil on the right.

Diesel engines just beginning to be placed in the hands of the public as tractor power plant installations. The Wright Aeronautical Corporation established standards of performance for lubricating oils to be used in their high output aircraft engines which apparently could be met only with a suitable base oil and a proper compound. At about the same time, the Caterpillar Tractor Company established standards of performance for Diesel engine lubricants which apparently could be met only by a suitable combination of base stock and compounds. In neither instance, however, did the foregoing companies specify directly the use of compounded oils, but they established engine performance requirements for the lubricants which the oil technologists were able to meet only through the use of compounds.

The adoption of "approved lists" of lubricants by these companies for their respective engines served to stimulate a program of research which has brought forth almost unbelievable improvements in lubricants designed especially for use in high output engines. Inasmuch as Diesel powered tractors offered a more profitable market from the standpoint of both volume and prices obtainable for improved lubricants, the major portion of the effort on additives was directed toward improvements in Diesel engine lubricating oils, and it has been in the field of Diesel engine lubrication that the most outstanding improvements have been made. As was to be expected, however, much of the information obtained in developing oils for both aircraft and Diesel engines has been used to make improvements in the best grades of lubricants sold for ordinary passenger car use.

The easiest way to classify the different additives now in commercial use is to group them according to their most desirable property or intended function, rather than to group them according to chemical composition. Aside from pour point depressants, V.I. improvers, etc., which affect principally some physical property of the oil, additives in use today can be placed in one or more of the following groups: A. Oiliness agents, B. Detergents, C. Oxidation inhibitors, D. Bearing corrosion inhibitors, and E. Film strength agents.

The principal function of oiliness agents is to reduce wear under normal operating conditions where seizing or galling is not a factor, although reduction in friction may also be accomplished by the addition of an oiliness agent. The temperature or pressure at which galling or seizing may take place is also usually affected favorably by the addition of the wear reducing agents. This class of additives appears to aid in establishing smoother working surfaces and simultaneously to protect the working surface of cylinder bores from the corrosive effects of the combustion gases. This frequently results in a materially improved relationship between ring faces and cylinder walls, whereby blowby past the top ring is reduced and oil deterioration and contamination are likewise reduced. Through this latter action, effective oiliness agents may contribute toward crankcase cleanliness and reduced sludging. The reduction in wear, however, is the most outstanding improvements afforded by this class of additives. In high output engines, the cylinder and ring wear has been known to be reduced by as much as 75 percent by the addition of the proper oiliness agent.

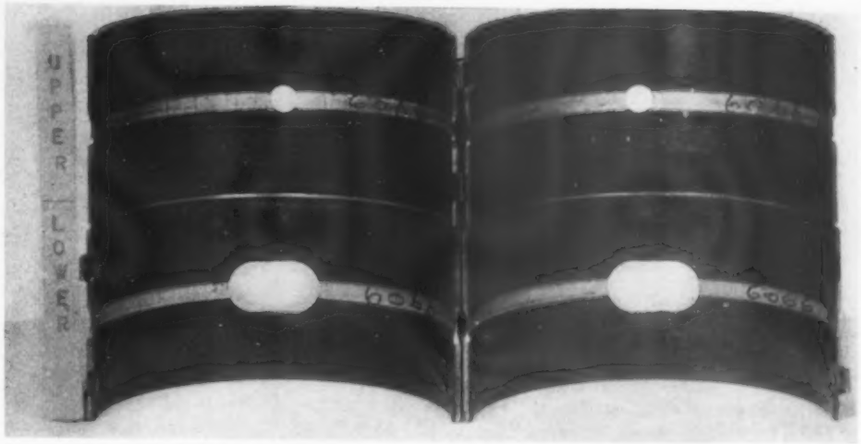
Chemically, the oiliness agents in most common use today contain oxygen, but may also contain sulphur, chlorine or phosphorus. Esters of synthetic acids produced by catalytic oxidation of high molecular weight aliphatic hydrocarbons, esters of fatty acids, esters of chlorinated fatty acids, esters of sulphurized unsaturated fatty acids, esters of phosphorus bearing acids and metal soaps or salts or high molecular weight acidic organic compounds are all found in oils now upon the market.

The function of detergents added to crankcase oils is to improve engine cleanliness, and to prevent ring-sticking and the accumulation of lacquer deposits. Detergents are sometimes erroneously called "sludge solvents" and it, therefore, should be pointed out that the action of detergents in crankcase oils is to suspend or disperse the deposit forming materials in the body of the lubricating oil rather than to dissolve these impurities. The beneficial effect of detergents in high output engines is easily demonstrated, and the first major step in improving lubricating oils for Diesel engine service was obtained through the introduction of detergents. The most power-

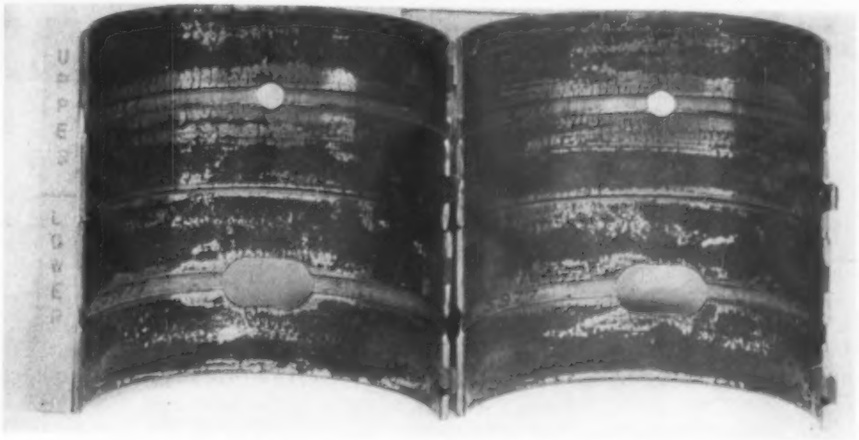
ful detergents in use to date are all metal bearing compounds and consist of salts or soaps of acidic high molecular weight organic compounds; carboxylic acids, sulfonic acids, phenols, etc. While this type of compound produces almost phenomenal results in keeping engines clean and rings free when the oil is not used too long between drains, it was soon found that this type of compound actually accelerates oil oxidation through the catalytic effect of the metal constituent. The next step, therefore, was to develop oxidation inhibitors which would poison or offset this undesirable effect.

Oxidation inhibitors are designed to inhibit or retard the rate of deterioration of lubricating oil under the influence of heat and oxygen. It is obvious that any reduction in the deterioration of the base mineral oil during the useful period of life in the crankcase will contribute toward engine cleanliness. However, a principal function of oxidation inhibitors is to keep the formation of corrosive organic acids to a sufficiently low level to permit the use of copper-lead and cadmium-silver bearings. Simultaneously the thickening rate and sludging tendency are favorably affected. The most successful oxidation inhibitors contain either sulphur, phosphorus or phenolic groups, or some combination of these. The sulphur is usually present in the sulphide type of linkage, while the phosphorus should be in the trivalent state. For example, sulphonic groupings give comparatively little oxidation inhibition whereas sulphides are usually effective. Likewise, tricresylphosphate gives practically no oxidation inhibition but triphenylphosphite has been used extensively as an oxidation inhibitor.

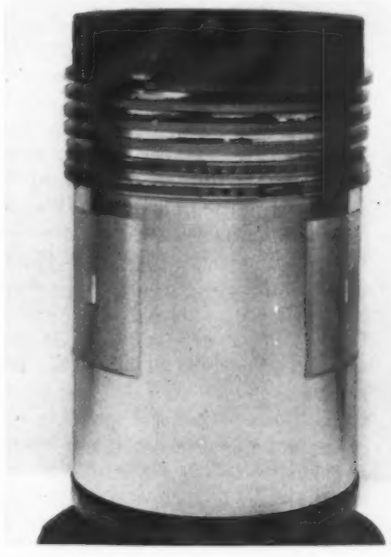
When bearing corrosion was first observed with copper-lead and cadmium-silver bearings in 1934 and 1935, much effort was devoted to developing bearing corrosion inhibitors which would make the bearings passive or immune to attack from organic acids formed in the crankcase oil. In the last few years, however, the viewpoint has become fairly well accepted that the most successful way to prevent bearing corrosion is to prevent the formation of corrosive acids through the use of oxidation inhibitors. As a further step toward reducing bearing corrosion some oils have been made alkaline in nature before they are placed in the engine. Alkalinity is secured through the use of alkali-metal salts of extremely weak or non-corrosive acidic bodies. This type of metal compounds such as the calcium or barium salts of high molecular weight phenolic bodies presents a source of reserve alkalinity which exerts a neutralizing or buffering action against the stronger corrosive acids developing during use. In this respect, this type of metal compound can be considered to represent a bearing corrosion inhibitor. Organic phosphites and certain sulphur compounds appear to render cadmium-silver bearings less susceptible to corrosion by organic acids, but have little or no effect on the susceptibility of copper-lead bearings to attack by organic acids.



Above, copper lead bearings run on compounded Diesel engine oil; no corrosion, bearings in good condition. Compare with illustration directly below.

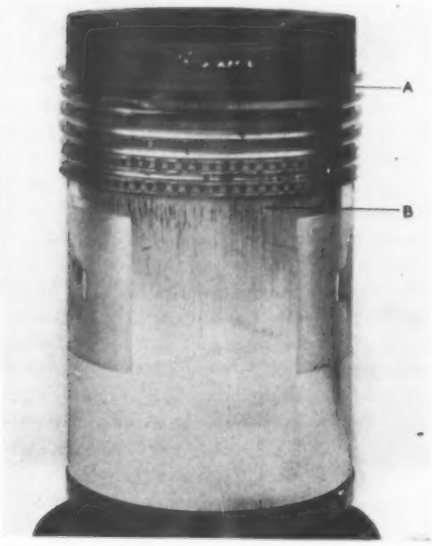


Above, copper lead bearings showing evidence of corrosion after testing on straight mineral oil. These bearings were tested under same conditions and the same engine as those shown at top of page.



Above, excellent load carrying ability of compounded engine oil tested under same conditions as piston shown at right. Comparative photos by courtesy of Caterpillar Tractor Company.

Below, unsatisfactory results of tests for load carrying ability of engine lubricating oil. Piston is scratched by metal particles from rings and liners.



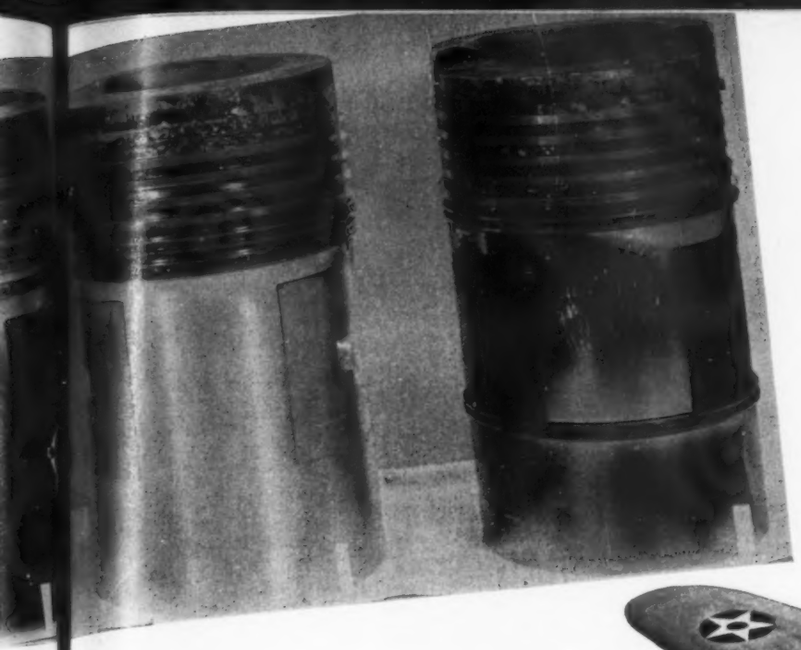
While compounding has revealed great improvement in load carrying ability and other performance characteristic, incorrect compounding is worse than none at all. At right is shown a special chemical plant in which complex compounding agents are made. At far right, three pistons, from left to right: failure of straight mineral oil; same oil as used in first test plus suitable compound showing excellent results; the same oil as used in both previous tests plus unsuitable compound showing failure worse than with straight mineral oil.

The addition of film strength agents such as sulphur phosphorus and chlorine in suitable compounds appears to decrease the tendency toward scratching, galling or seizing under adverse conditions of temperature and pressure, but it is seldom the practice to add a compound which furnishes only this feature. Many of the oiliness agents, detergents and oxidation inhibitors carry one of these "anti-welding" elements. There is much evidence to indicate that anti-welding agents may cause undesirable effects unless accompanied by oiliness agents.

The tendency for the rings and cylinder walls to become scratched, scuffed or galled (depending on the nomenclature preferred by the reader), increases greatly as the speed, temperature and b.m.e.p. of the engine are increased. Many engines have operated for years with negligible difficulty from scratching or galling of rings and cylinders, but when it has been attempted to draw more power from later models by increasing speed and b.m.e.p. which results in higher temperatures and pressures, the new engines have sometimes failed to the point of destruction through scratching or galling of ring faces and cylinder walls. The rate of wear when scratching or galling is absent is usually of the order of magnitude of half a thousandth to five thousandths of an inch in a five to six inch diameter cylinder per 1000 hours, depending on the lubricant and operating conditions, and the engine may run for many hundred or even several thousand hours with rates of wear within this range. Then for some reason of circumstances not always clear, the rings and cylinder wall start "scratching" each other, and in as little as 30 minutes of continued operation, radial "wear" on the rings may amount to half or more of their radial width and the cylinder barrel may show an increase in diameter as much as 150 thousandths of an inch. While this sword of Damocles hangs over a high output engine all the time, it is perhaps most likely to cause difficulty during the first hundred hours of operation.

It is incorrect to speak of such loss of metal from ring faces and cylinder walls as "wear." The mechanism of this loss of metal is distinctly different from that which accounts for the type of wear experienced the rest of the time. The latter type of wear is commonly believed to be due to mechanical abrasion or corrosion followed by abrasion; whereas the loss of metal and destruction of the frictional surfaces when scratching or galling takes place is apparently due to welding effects. At points of greatest stress between rings and cylinder wall, actual or incipient welding occurs as the energy required to maintain motion becomes sufficiently great to raise the temperature of the metal at points of contact to the melting point. Instantly, as the stress is relieved by softening of the points of resistance, solidification takes place and the continued motion of the ring tears out the welded area. The scratched areas do not appear to be easily wetted by the lubricating oil and instead of the scratched area healing or polishing over, the scratched area often spreads rapidly in all possible directions, i. e., both up and down and around the cylinder wall and ring faces. The rapid spreading of the area of destruction is undoubtedly accelerated by the particles of metal which are torn loose and which then travel up and down with the rings. It is easily seen how anti-welding agents in the lubricating oil might alleviate scratching difficulties.

Other factors remaining the same, both the nature of the metal surfaces and the composition of the lubricant are important factors in the probability of scratching occurring. In general, the tendency to scratch is increased as the hardness (tensile strength) and ductility of the liner surface material are increased. If the points of contact under excessive stress can crumble away before sufficient energy is absorbed to cause softening, welding is not apt to occur. Hence, anti-scratching rings have been developed which carry deep grooves at right angles to the cylinder axis in the face contacting the cylinder. This serrated surface can relieve the stress more readily than can a smooth, continuous surface because of the less amount of energy required to plough out an accommodating furrow. Such rings might be expected to show higher rates of wear, but excess wear, from a distress condition, would occur only at a time when complete destruction of the frictional surfaces would be experienced with smooth faced rings. Also the deep serrations or grooves carry additional lubricant to the places where most needed. As to be expected, much evidence indicates that too smooth finishing of the cylinder wall may aggravate the tendency for a given engine to scratch. By studying the engine materials, surface finishes and lubricants, all in conjunction with each other, much progress has been made in avoiding disastrous failures from scratching in service. Just as the Caterpillar Tractor Company was foremost in overcoming ring sticking by the use of detergent type lubricating oils, this company has also led the way in the effort to overcome failure from scratching. The Caterpillar Research Department has developed a standardized engine test procedure for lubricant load carrying ability which apparently gives excellent correlation with field results on many types of engines with a wide variety of lubricants. From a careful consideration of all observations available, it appears that as far as the lubricating oil is concerned, both the mineral oil and the additives present are important factors in the occurrence of scratching or galling. It, therefore, seems in order to take maximum ad-



Below, under the impetus of war a huge fleet of planes for exacting service is being built with rigid specifications for lubricating oil. If the industry had to rely on selected crudes from limited sources it might be unable to meet the demand; fortunately the science of compounding lube oils properly to meet difficult conditions has enabled the industry to supply the demand from a large variety of crudes and in ample quantities.

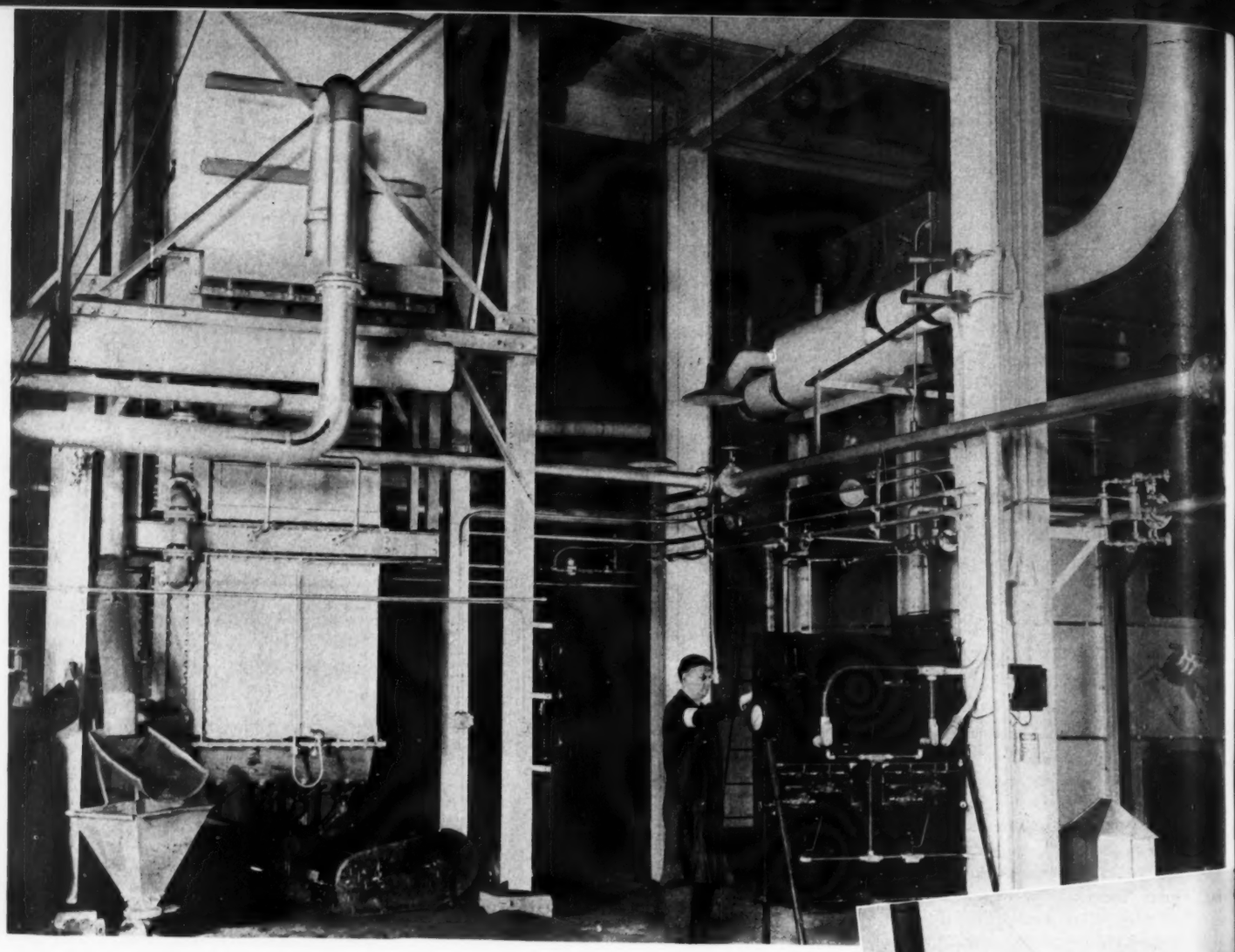
vantage of all protection available against scratching in the selection of the mineral oil and additives respectively.

Where the mineral oil is to be improved in a number of respects by the addition of additives, it is often possible for the chemist to build into the organic compound the essential groups or structure required to furnish the different properties desired. Many of the compounds in actual use have been synthesized on this basis and therefore perform more than one function. A certain chemical compound widely used in Diesel engine lubricants is simultaneously an oiliness agent, detergent, oxidation inhibitor, corrosion inhibitor and film strength agent. To emphasize any one of these properties, additional specific compounds are added. Many of the compounds in use, of course, perform only one or two functions. Thus, it is seen that for the most severe service, the highest quality mineral lubricating oil from the standpoint of oxidation resistance and carbon formation should be selected, and additives should be incorporated to improve oiliness, detergency, oxidation resistance, bearing corrosion and film strength. All of the hundred or more brands of oil now on the approved list of a major Diesel engine manufacturer conform to this pattern. Another major Diesel engine manufacturer also recommends oils of this type. For less severe service, the amount of compounding can obviously be reduced, either by making a proportionate reduction in all of the different types of compounds or in reducing only those agents which are needed the least for the lighter service. Until recently, the fully compounded type of oils represented by the approved Diesel engine lubricating oils were not considered necessary for gasoline engines. However, with the heavy loadings being imposed upon some commercial pieces of gasoline equipment, it has been found that the use of the fully compounded oils is well justified. Consequently there has been a marked tendency to speak of these oils developed especially for Diesel engines as "severe duty" or "heavy duty" oils, which omits any apparent limitation to Diesel engines. As a result of exhaustive tests, the Navy uses only the fully compounded type oils described above in Diesel engines, and the Army apparently will use this type oil in both gasoline and Diesel engines.

Before concluding, it should be pointed out that while improvements approaching miracles have been made in some cases by the addition of compounds to lubricating oils, the indiscriminate use of additives may do more harm than good. Additives represent "medicine" and just as one would hesitate to give or take medicine for the human body without medical knowledge, so should one use caution in adding compounds to lubricating oils. Where success has been achieved in the use of additives, such success has been the result of a great deal of study and research on the part of those responsible for the prescription. As a result of the outstanding improvements obtained with a relatively few well-chosen compounds, many new "compounds" will be offered, and before either a new or old compound is accepted, either thorough investigation should be made or expert opinion obtained, or both, as to the exact problem at hand. Certainly all compounds are not alike in their effects, and also all oils do not respond the same to the same compound. The accompanying photograph of three Diesel pistons illustrates how a suitable compound made a great improvement over the same oil without any compound, whereas an unsuitable compound made the oil worse.

A most urgent question yet to be answered generally is "How far should the refiner go in compounding oils for everyday use?" Should the Diesel type additive be incorporated in passenger car oils, and how heavy should be the dosage? Are there any disadvantages, aside from cost, resulting from the incorporation of the Diesel additives in passenger car oils which offset the advantages? Can aircraft engine oils be improved further by adopting modifications of the Diesel compounds? Will passenger car operators and aircraft engine operators pay a premium for a greatly improved lubricating oil? These and other questions are now being studied in many quarters and only the future can tell what the answers will be. The answers to some may come before the war is over, but the answers to others may have to wait.

In conclusion, it may be stated that the combined cooperation of engine builders, oil refiners and chemical manufacturers has led to the development over the past decade of lubricating oils of superior quality. Through the use of these new type oils, engines of exceptional performance will operate successfully against the enemy. This is truly a war of machines, and the nations with the best fuels and lubricants can build and operate the best machines.



THERMOFOR Provides Simple Process for Production of Petroleum War Products

Based on Moveable Bed Catalyst, The TCC Process

Produces Aviation Base Stock, Alkylate for 100 O. N.

Gasoline, Butylenes for Synthetic Rubber and Toluene

A NEW FORM of catalytic cracking process involving the principle of a moving catalyst bed has lately reached the stage of large-scale practice. It is called the Thermofor Catalytic Cracking (TCC) process, and was developed by the Socony-Vacuum Oil Company, Inc. Engineering of new projects is in the hands of The Lummus Company and E. B. Badger & Sons Company.

The origin of TCC goes back a number of years, when the Thermofor regenerating kiln was invented for solving the problem of continuously regenerating the spent decolorizing clay used for filtering lubricating oils and other petroleum products. Previous to the invention of the Thermofor kiln, spent clay was being regenerated (and still is to a large extent at the present time) in various types of rotary drums and furnaces in which temperature control was difficult, with the result that burning was uneven and the useful life of the clay limited to a few cycles.

The principle of the Thermofor regenerating kiln, which now forms an integral part of the Thermofor Catalytic Cracking Process is to allow the spent clay to pass by gravity flow from the top to the bottom of a vertical shell against a rising column of air, which burns off the car-

bon deposit on the clay particles. The interior of the vertical shell is furnished with a number of perpendicular steel tubes through which circulates a stream of molten salt as a heat transfer medium. Normally, the carbon on the clay furnishes enough heat for the combustion and the molten salt then has the function of keeping the temperature within bounds. This assures that the clay will be regenerated at the right temperature, and with so little loss of decolorizing power that no more than two percent make-up of fresh clay is needed to maintain its efficiency at a high level. The general arrangement of a Thermofor clay regenerating kiln is shown at the top of the following page. To date, these kilns have been installed in refineries in Olean, Paulsboro, Beaumont, Buffalo, Brooklyn, and India.

During the period of its development the Thermofor clay regenerating kiln underwent a number of modifications. In its final form the downward flow of the clay is uniform, attrition is reduced to a minimum (less than one percent of dust) and the temperature is regulated to a nicety. To extend this principle of continuous counter-current clay regeneration to the operation of a moving catalyst bed was a relatively short step. The thermofor kiln had shown how easy it was to let an ascending current of a gaseous substance (in this case air) act countercurrently on a descending stream of a granular solid. Take a Thermofor clay kiln, substitute for the spent decolorizing clay a granular cracking catalyst and let this catalyst descend against a rising stream of vaporized gas oil, and you have a continuous catalytic cracking process with a moving catalyst bed. The cracked petroleum products pass out at the top, and the spent catalyst issues from the bottom, from whence it may be taken to another Thermofor kiln for burning off the carbon deposit and returned to the column of moving catalyst.

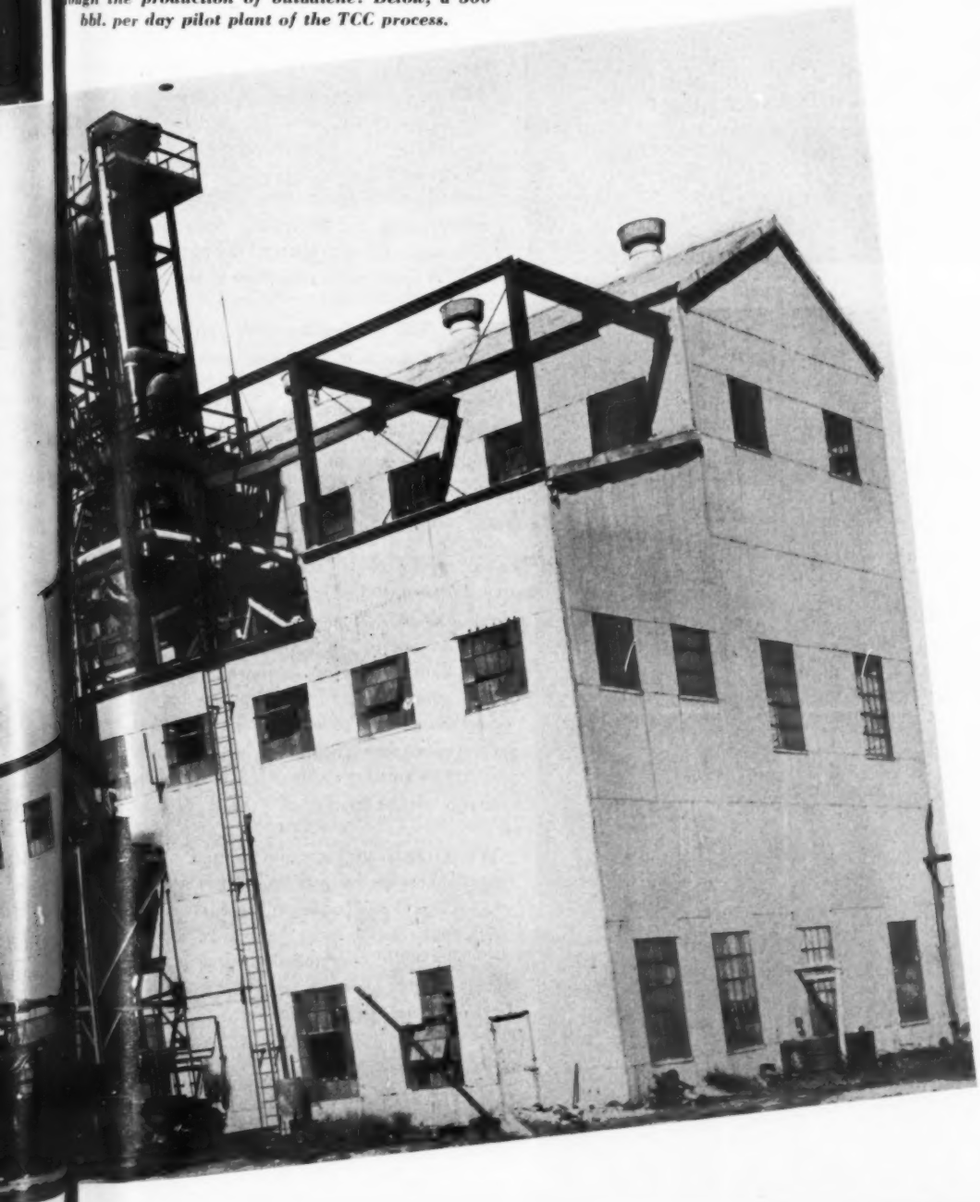
The TCC process works on gas oils from light selected stocks to wide cut, very high end point stocks that will vaporize at slightly below the reaction temperature. The overall objective is to produce a maximum yield of high quality gasoline and a minimum yield of lighter gaseous product and carbon. The layout of a TCC plant may be gathered from the very generalized diagram shown on p. 86, which may be taken to represent an installation rated at 20,000 bbl. per calendar day. An initial charge of a reduced crude is preheated by heat exchange and mixed with recycle gas oil from the bubble tower. The mixture passes through one side of a fired furnace where its temperature is suitably raised and from whence it is vaporized in a flash chamber. The overhead from the tar separator is superheated in the other side of the fired furnace and passed in vaporous form into the bottom of a Thermofor catalytic reaction tower having a capacity of 10,000 bbl. per calendar day (in this plant there are two such towers). In the reaction tower the vapors rise against a descending column of clay cracking catalyst. The cracked vapors go to a fractionator where the gasoline is conventionally stabilized at 400 deg. F. end point. In addition, a side stream is taken which meets specifications for No. 2 Fuel without further treatment. The bottoms from the fractionator are recycled to the catalyst case.

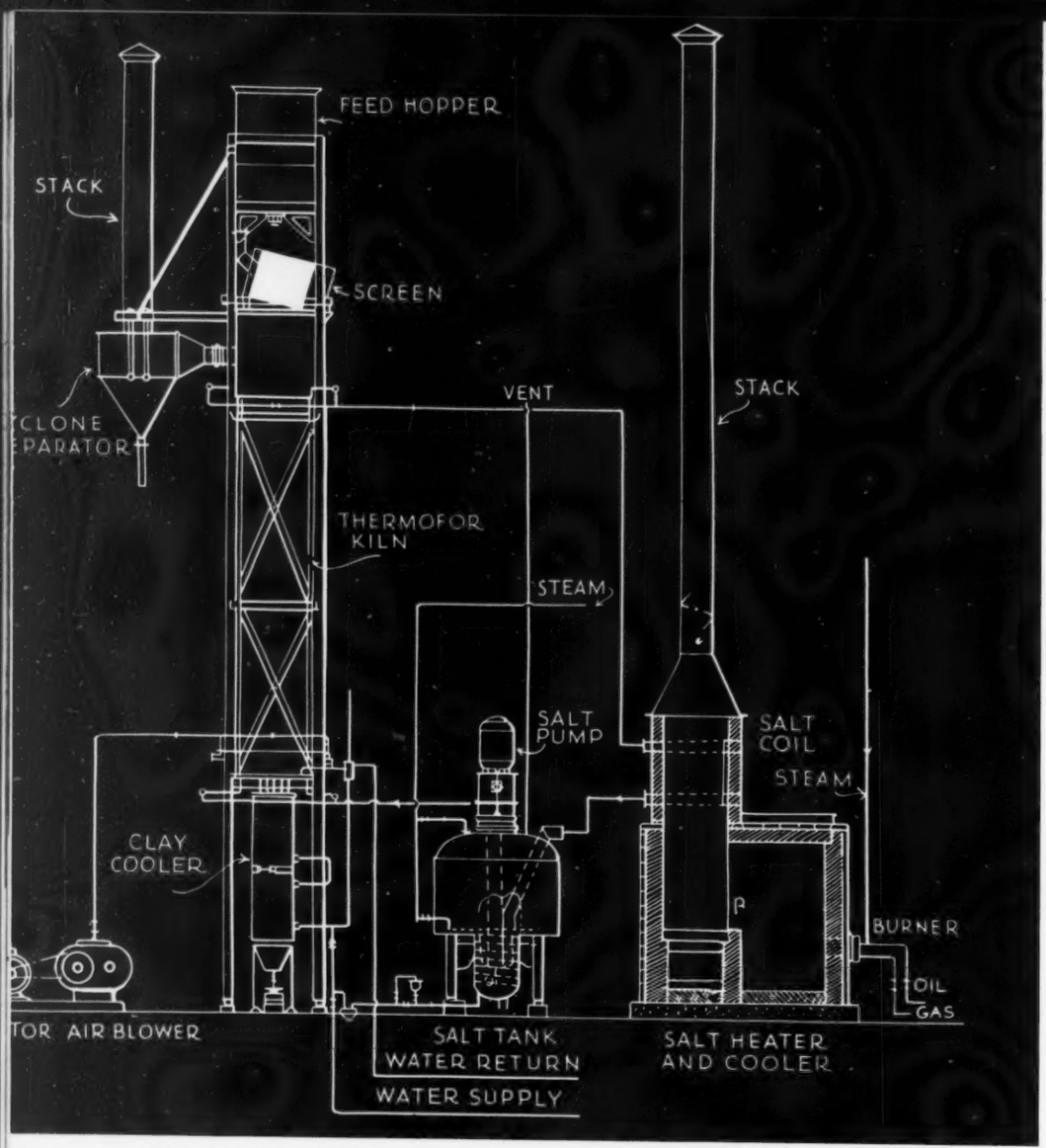
In the meantime, the spent catalyst that flows from the reaction tower is taken to a Thermofor regenerating kiln, where the carbon deposited on the grains of catalyst is burned off. Here the burning temperature is under full control by means of a circulating stream of a heat transfer medium, which absorbs superfluous heat and is converted into much useful stream; the regenerated catalyst is returned to the feed hopper above the catalyst case. The make-up of fresh catalyst per bbl. of total feed charge is very small and it is never necessary to replace the entire charge of catalyst. The small amount of clay fines from the Thermofor regenerator may be used for percolation or reworked for catalyst. The operating personnel per shift consists of one fireman, one operator in charge of the distilling equipment, one man in the control room, and one general utility man.

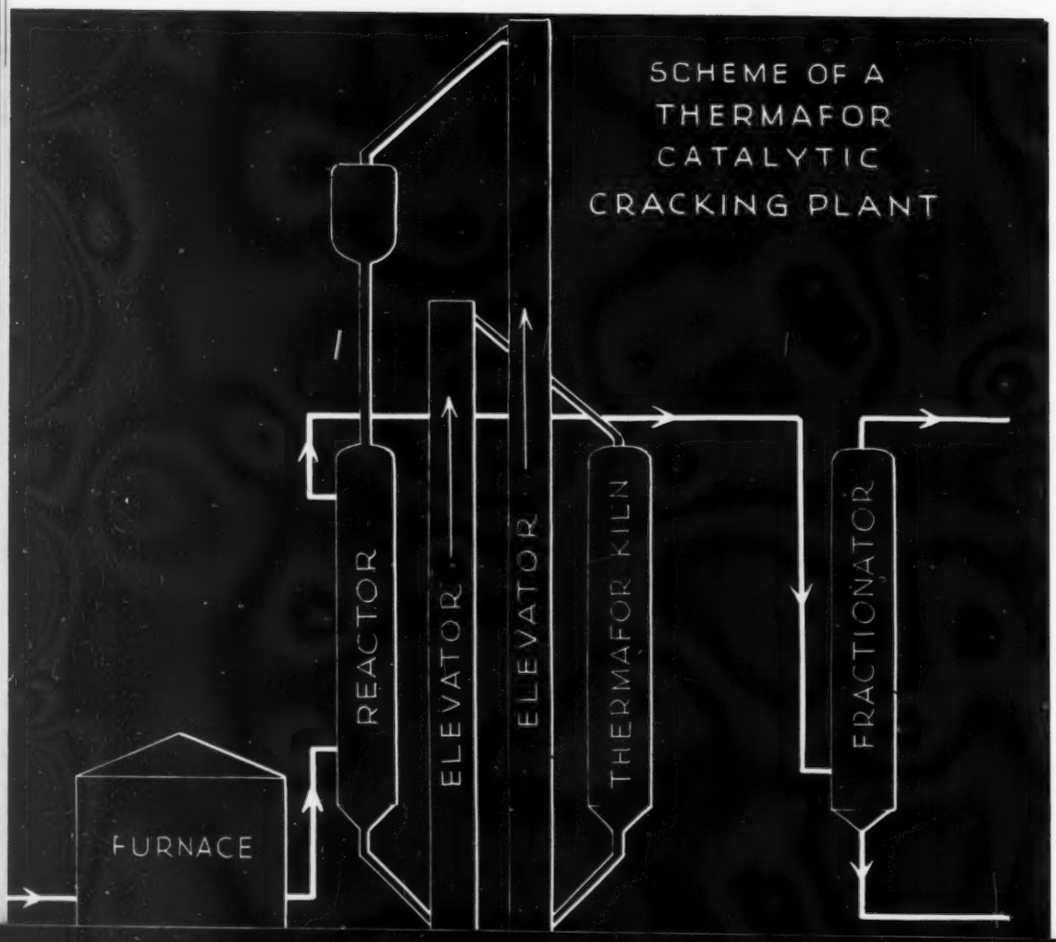
This TCC process appears well adapted to fill the present need for a relatively inexpensive and simple process for obtaining first class aviation base stock, alkylate for 100 octane number gasoline, butylenes for artificial rubber, and nitration-grade toluene for high explosives. It has passed the pilot plant stage and semi-commercial scale of operations since early in 1941, and at least one unit for treating 20,000 bbl. of distillate per calendar day is under construction at a cost of about $2,400,000 or approximately $120. per bbl. of rated daily capacity.

An important consideration in the present conjuncture is that erection of a TCC plant makes relatively moderate demands for critical materials. Engineering specifications call chiefly for simple structural forms, light steel plate of carbon steel, gray iron castings and other fittings, and readily available low chrome and nonferrous alloy tubing. Only the tubes and inter-

ft, a Thermofor clay regenerating kiln from which developed the Thermofor Catalytic Cracking ocess that may contribute to the rubber program rough the production of butadiene: Below, a 500 bbl. per day pilot plant of the TCC process.







nal fixtures of the Thermofor kiln require silicon-chrome 4-5 steel. Pumps, blowers, heaters, towers, electrical equipment, etc., are conventional.

A TCC unit may be run (1) for maximum 400 deg. F. end point gasoline with high liquid recovery; (2) at higher temperatures for maximum butane-butylene; or (3), at some intermediate condition. Once-through operation gives satisfactory yields of debutanized 400 deg. F. end point gasoline on distillate stocks. With recycling operations up to one part of recycle to one part fresh feed, the yield is quite good. Recycling under specified conditions may be used to obtain high yields of a butane-butylene cut containing a high percentage of butylene, depending on type of stock and operation. The butane-butylene cut varies from 6 to 15 percent of gas oil in normal operations, and as high as 20 to 25 percent in suitably controlled operations.

The gasoline obtained in the gas oil operation may be retreated in a TCC unit to produce aviation base stock. Depending on the type of stock and the type of operation, conversion has amounted to 85 to 95 percent. This base stock has a satisfactory oxygen-stability, acid heat, and army gum; it may be blended with relatively small amounts of alkylate and TEL to produce 100 octane gasoline. The catalytic reactor and regenerating equipment may be conveniently installed in conjunction with furnaces and distillation equipment available in existing thermal cracking units. This expedient may result in a reduction in investment to about half the normal investment. The catalytic reactor and regeneration systems can be readily designed in smaller sizes with proportional savings in costs, thus making the process attractive to the small refiner.

The TCC process as above outlined relates to catalytic cracking of gas oil and catalytically retreating the gasoline produced to obtain aviation base stock. Hardly less important at the present time is the production of butylene for butadiene production for the manufacture of artificial rubber and toluene for TNT. For production of 50,000 tons of butadiene a year there would be needed two TCC units, each cracking 10,000 bbl. of gas oil per calendar day. The amount of butylene produced would be 2400 bbl. per calendar day, which would be the equivalent of the 50,000 tons of butadiene per year. In addition, this plant will be producing highest quality aviation gasoline, motor gasoline, and catalytic gas oil, of which 75 percent is No. 2 Fuel. The total investment in such a plant, including everything, is said to amount to about $1200 per bbl. of daily charge of gas oil.

While the ready accessibility and relative inexpensiveness of this process gives it a lively importance as a contribution in the current emergency, it appears also to have the quality of an economical and easily operated peacetime plant for high grade motor gasoline, aviation gasoline, high grade Diesel and furnace oils.

Information supplied by "World Petroleum"

Rapid and reliable heat transfer in a refinery depends upon the condition of the thousands of small tubes within the heat exchangers which are the heart of the plant. Scale, films, wax and carbon clog the passages on the shell side as well as the tube side thus reducing heat transfer and causing pressure drop.

Periodic cleaning is essential. In removing and cleaning care is necessary to avoid misalignment, strain and injury to the thin metal tubes. Here are two methods to withdraw the tube bundle from the shell: 1 — Steel rods or cables passed through several tubes and fastened to the floating tube sheet at the opposite end thus placing the load on the sheet and permitting removal of the bundle without damage. 2 — Boards placed on the lower half of the bundle after it has been partially withdrawn from the shell; the boards to be extended lengthwise parallel to the tubes then slings passed around the bundle so that the weight is supported on the baffles or support plates which rest on the boards.

A forged steel eye bolt screwed into the fixed tube sheet facilitates pulling and lifting.

It is important that the dead weight of the bundle should never fall on individual tubes. It should be carried on the tube sheets, support plates or on wood blocks shaped to fit the periphery of the bundle.

Care in these details of handling during cleaning and inspection will insure a correct fit in replacing bundles and avoid the replacement of tubes which wastes both time and valuable material.

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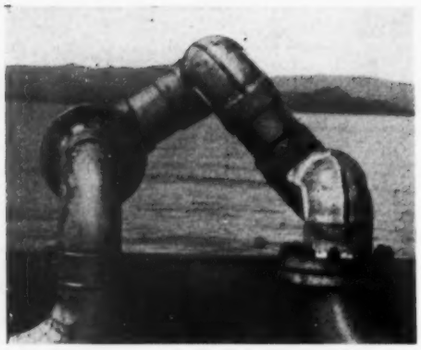

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THERMAL CRACKING FACILITIES

(Continued from page 77)

Type Unit	Daily Cap. Cracking	C_3H_6 yr. Tons	Iso-C_4H_8 yr. Tons	Converted to operate at Temp. Deg. F
High Press.	5000 bbls.	3000	4000	1150 F

Gyro: Same without any changes necessary.
De Flroez: Change operating pressure from 100 lbs. to 15.

The pressure of the high pressure units cited above was 350-500 lbs. before converting, and the capacity is that before converting. In other words the capacity of a high pressure unit after conversion is the same amount of fresh feed it charged before conversion. The additional gas plant equipment has to be supplied, of course, and no recycle above 1-1 is used if naphtha is charged.

If a Gyro unit charges, under normal operation of 1080°F temperature, 6000 bbls. of reduced crude oil per day, it can be operated at 1225°F and produce at least three times the amount of butadiene that will be made when operating on reduced crude at 1150°F. The increase in temperature produces more of the C_4 material and the concentration of the butadiene is raised to 30 percent as compared with a concentration of 14 percent with the operation conducted at 1150°F. The Gyro with a daily capacity of 6000 bbl. of reduced crude when operated at 1225°F. will produce annually about 9000-10,000 tons of butadiene and at the same time will produce about 8000-9000 tons of isobutylene and some 3000 tons of butylene (normal).

We have in this country several hundred thermal units of the Cross and Dubbs types. Theoretically, about half of them are not in useful production if our national gasoline consumption is down 50 percent as compared with normal times. Several of these units are down because they have been replaced by the catalytic units of the Houdry type, and they will never go back into operation for the normal production of gasoline for motor cars. The art has changed so rapidly that they are out of date for the purpose. It is our best bet for economy to operate on units of this type, for the pressures of the new operation will be lowered, thus making their operation safe as compared with their operation at several hundred pounds pressure. The steel and instruments, valves, tanks, personnel to operate, etc., are all there and ready for conversion and use.

The daily capacity (charge to cracking coils) of the U. S. A. is estimated to be around 3,000,000 bbls. per day. If we assume that it is all high-pressure (for sake of easy computation) there is at least 1,000,000 bbls. per day of idle capacity. With conversion of these units the easy and mild way—to operate at the mildly increased temperature of 1150° F. instead of at 1225°-1400° F. —we can safely assume that the capacity to crack will be the same number of barrels of fresh feed. This is 1,000,000 bbls. per day. The yields of butadiene will be approximately 600,000 tons, and 800,000 tons of isobutylene, which is more rubber making material than will be needed by 30 percent, according to the published figures.

Recent studies have indicated that the conversion of high pressure cracking units can be accomplished in six to eight months time if the proper priority ratings on the repair material is given by Washington. Compare with this the estimated 18-21 months, as estimated last spring when the catalytic plants were planned and signed up.

Recently there have been rumors to the effect that one company has perfected bath tub rubber. The rumor is to the effect that isobutylene can be run to a bath tub in the presence of a catalyst, and the scum which comes off the surface (such as cream would come from settled milk,) after a squeeze or two to remove reagents will yield Flexon, a rubber which is going into the manufacture of rubber products at the present time. If this is true we need to convert only 500,000 bbl. of our estimated cracking capacity to high temperature operation for the production of butadiene and butylene. There will be obtained as a by-product, at the same time, an amount of aromatics amounting to half the estimated annual requirements for aviation blending, if the operation is carried on at the 1150° F. temperature, or an amount equal to the total requirements if the thermal units are converted to run on naphtha and at the maximum temperature of 1350°-1400° F. In other words, we can secure the rubber raw materials and the aviation "must" aromatics, amounting to some 1,500,000 tons per year, from the conversion of existing cracking equipment, and it can be done in time for this war, not the next one.

Since it is a fact not appreciated by most people that the Soviet Union has probably pioneered synthetic rubber on a greater scale than any other nation, we may well profit by studying their published results as an aid to our guidance. It is believed that the work of S. V. Lebedev through the years 1928 to 1935 is a classic on the subject. These data of Lebedev have been checked in many cases by the writer and found to be very reliable. Mention should be made of Lebedev's work on the analysis of butadiene fractions, comparing the bromination method with the maleic anhydride method. This work has pointed the way for us, and has saved valuable time. The author's work on thermal "means" for the production of butadiene has been checked and found to be very accurate both as to his temperatures and his time of reaction. His pioneering work on the necessity for having a relatively large amount of inert gas or steam present if maximum

(Continued on page 92)

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(Continued from page 88)

yields of butadiene are to be obtained is worthy of special note. His work has also been known in the field of ethyl alcohol decomposition for the production of butadiene in connection with Buna rubber. It is established that alcohol was the first raw material used to produce butadiene for rubber on a commercial scale both in Russia and Germany, the scenes of the greatest amount of synthetic rubber so far produced in the world.

Some particularly interesting data are published by B. V. Buizov (Journal of Applied Chemistry, USSR, 6, 1074-92, 1933) on the conditions necessary for the production of butadiene by vapor phase cracking of petroleum. The author's principal contribution in this work is exemplified by the following quoted material: "The principle which we used as the basis of the experiments consists in a heat decomposition of liquid petroleum products at elevated temperatures and under a vacuum so as to cause an evaporation of these liquid products in the lower temperature zone, while the vapors are then decomposed to simpler hydrocarbons. Here it is important to avoid the decomposition of the formed butadiene and even its further condensation. It was therefore necessary to establish such conditions of temperature, speed of the passage of the decomposing vapors through the hot zone, and a vacuum which would correspond with the highest yield of butadiene. In practice this is realized by an adjustment of temperature and the volume of the retort with the speed of feeding the petroleum product which is to be decomposed, establishment of a vacuum, and a most rapid cooling of the gases passing from the hot retort. The last operation is called "tempering." (*Note:* The translation should be "quenching" in our terminology.) Thus the important points of the method are, in succession: Evaporation of the original material, its pyrolysis in vacuo, and "tempering" the products of pyrolysis. The further stages of the process consist in the purification of the gaseous butadiene, followed by its polymerization to rubber. The author then concludes, "the preliminary laboratory experiments were carried out with gasoline in a small furnace. This furnace contained an iron tube 2 cms. in diameter. Table 1 gives the summary of the results, showing the amount of decomposed gasoline and the main products obtained from varying conditions (the pressure was close to normal and a vacuum was not used)."

"Table 1 shows that the above factors must exist: i. e. the highest velocity of feed and temperature. The amount of butadiene which is then formed, as evidenced in the recently conducted experiments in the plant "Neftgas" lies within the range obtainable in the usual vapor phase cracking."

"The average yield of butadiene was about 2.7 percent on the original kerosene and on crude oil it was 4.0 percent."

The author goes on to say that he obtained as high as 8 to 9 percent of butadiene from the high-temperature short-time cracking of gasoline. No vacuum was used in these experiments but he says "the yields were higher when a vacuum was used." He stated that the best temperature for maximum yields of butadiene was 780° C., which corresponds to 1436° F. He also states that he obtained as high as 17 to 18 percent of butadiene when using these conditions. The author took out a patent (in Russia) covering the pyrogenic decomposition of crude oil and its products with the use of two operations: (1) the vapors of crude oil fractions or residuum are first heated to 300-400° C., passed through a very short path where the temperature is maintained at 700-800° C. (2) the gases obtained after the heating to 700-800° C. are immediately expanded and exposed to contact with cooling surfaces. All these operations must be carried out under vacuum or in the presence of inert gases. (*Note:* The Cooke process maintained the conditions mentioned several years prior to this work.)

On page 1077 of the reference the author suggests that "However, in combining the preparation of rubber with that of other products also valuable for the industry, their amount should be adjusted in accordance with the purpose." He was talking about making the maximum amount of butadiene if a plant was to be installed, and then qualified his remarks as stated above.

The author points out that the maleic anhydride method of determining the percentage of butadiene in a fraction is a great advance over the bromination method and is more accurate.

It will be noted that these investigators appreciated the effects of short time and a temperature

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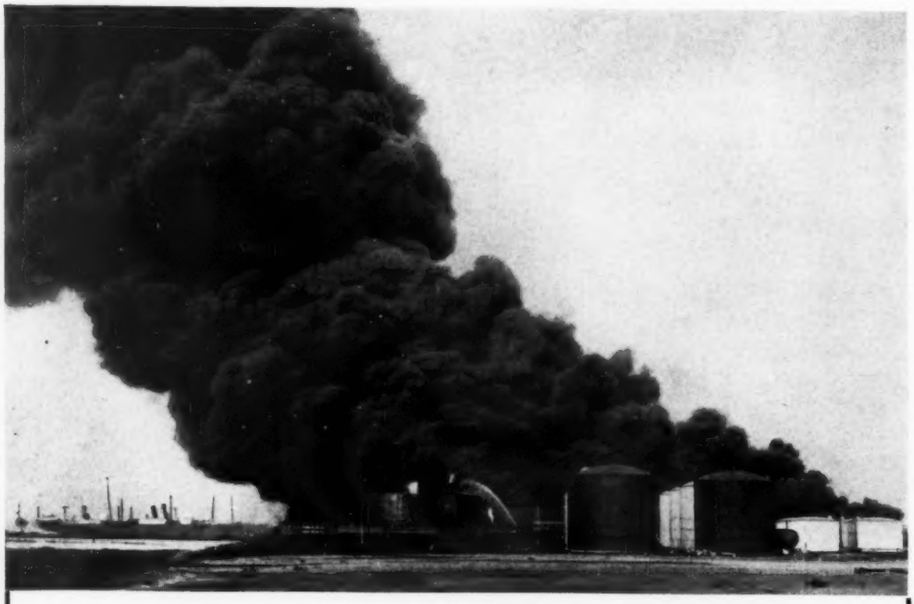

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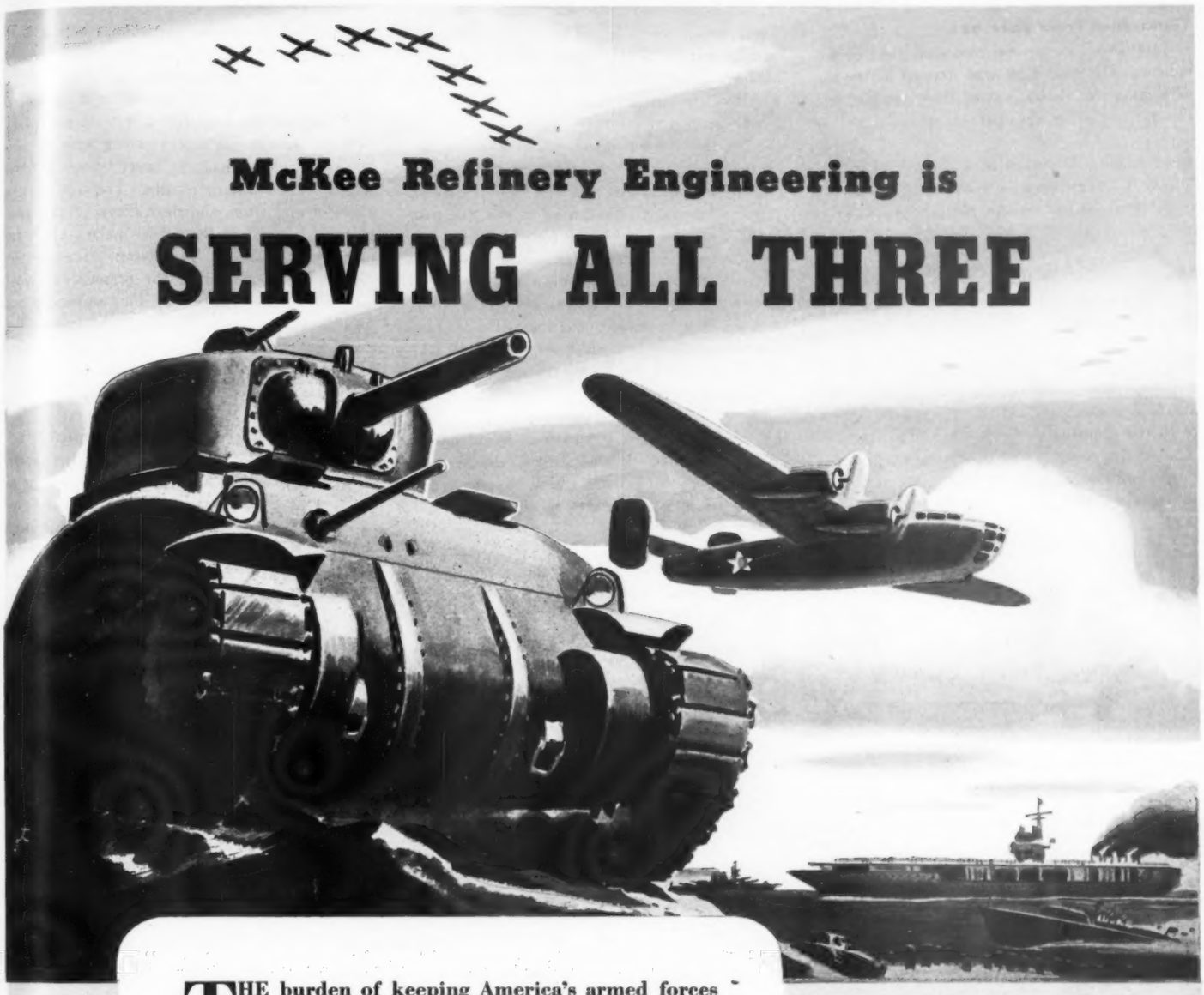

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(Continued from page 92)

of 1400-1440° F. for the maximum yield of butadiene. The short time was attained by the use of vacuum on stocks heavier than gasoline and this vacuum is the equivalent of steam, etc.

In an article published by B. V. Buizov (J. A. C., USSR, 6, 1074-1080) the author gives some very useful information on the purification of butadiene.

"Since almost all of the butadiene separates into the gas fraction it is only necessary to work on the gas fraction."

The author's methods for the separation of the butadiene were not perfected at the time this article was published. He did give some results of partial condensation of the butadiene fraction. The results were superior to the suggested method of absorbing the butadiene in kerosene or in water and then boiling out the butadiene in a fractionation operation. The author makes the remark that the bubble tower system needs overhauling as well as the whole rectifying system. (*Note:* Later articles showed this to be the main trouble with recovery yields.) He states that the concentration of butadiene was between 55 and 60 percent and this was known as technical butadiene and was later purified. Our work in America has really been started at this point, for we have worked out methods of selective solvents and azeotropic distillation methods on the 55-69 percent concentrate of butadiene, and this seems perfectly satisfactory. There are several processes available in America but the WPB are anxious to have these processes used which will take the least critical materials for the operation. This is sound judgment.

The author points out that care should be exercised in the use of temperature in the recovery of butadiene, for it will unite with other compounds present and cause losses of butadiene.

The author gives some particularly helpful data from page 1082 to 1092 on the subject of making rubber from the butadiene and these data are shown in terms we understand in this country. For instance, the Podbielniak method was modified and used in gas analysis along with the maleic anhydride method, the latter being a method which is used internationally. The data on the effect of impurities, and their effects on the polymerization speed of the rubber-making cycle are particularly helpful. This latter discussion includes the assertion that the presence of vinyl acetylene is very injurious. This statement has data to back it up in this country: in fact the acetylenes must be removed from butadiene down to microscopic quantities if quick and satisfactory polymerization is to be had.

A wide discussion is given on the subject of accelerators. The article indicates that the workers in USSR started out with such impure intermediate materials that the time of polymerizing to rubber was a matter of months at first, and was gradually reduced to hours. This is of interest, for a very good "case history" of the effects of impurities was thus built up. These data are of the greatest interest for those contemplating the study of the manufacture and sale of the intermediates for rubber, and for those who are charged with the responsibility of making the rubber from such intermediates. It is known that the USSR started out with metallic sodium as the polymerizing reagent, and found that there were other compounds with superior qualities later on.

Some helpful data are given on the subject of reaction vessels and their materials of construction. Iron was found to be particularly bad and was replaced by stainless steel. This has also been the experience of some of our investigators in America. Most technicians prefer stainless steel for the work.

This Russian author concludes from the data that the pyrolysis of petroleum has opened up new frontiers for the country as a source of many needed chemicals. Attention is directed to the large percentage of ethylene in the pyrolysis gases remaining after the removal of the butadiene. It amounts to as much as 43 percent, and as this material is one of the most desirable olefines for chemical synthesis, it is certain to be extracted as an intermediate material to be used in chemical synthesis. In fact, the author suggests that rubber become the by-product of the pyrolysis of petroleum, and not the main product sought. He ends his article by pointing out that, "There are other products, in addition to the butadiene, which, after a necessary conversion into a more valuable raw material, will give an inducement for a new direction to the technology of the organic compounds of the fatty acid series, substituting the existing vegetable and animal raw materials."

In view of the Russian published data it is of

(Continued on page 98)

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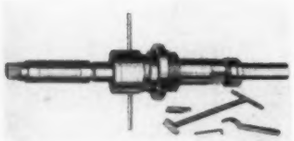

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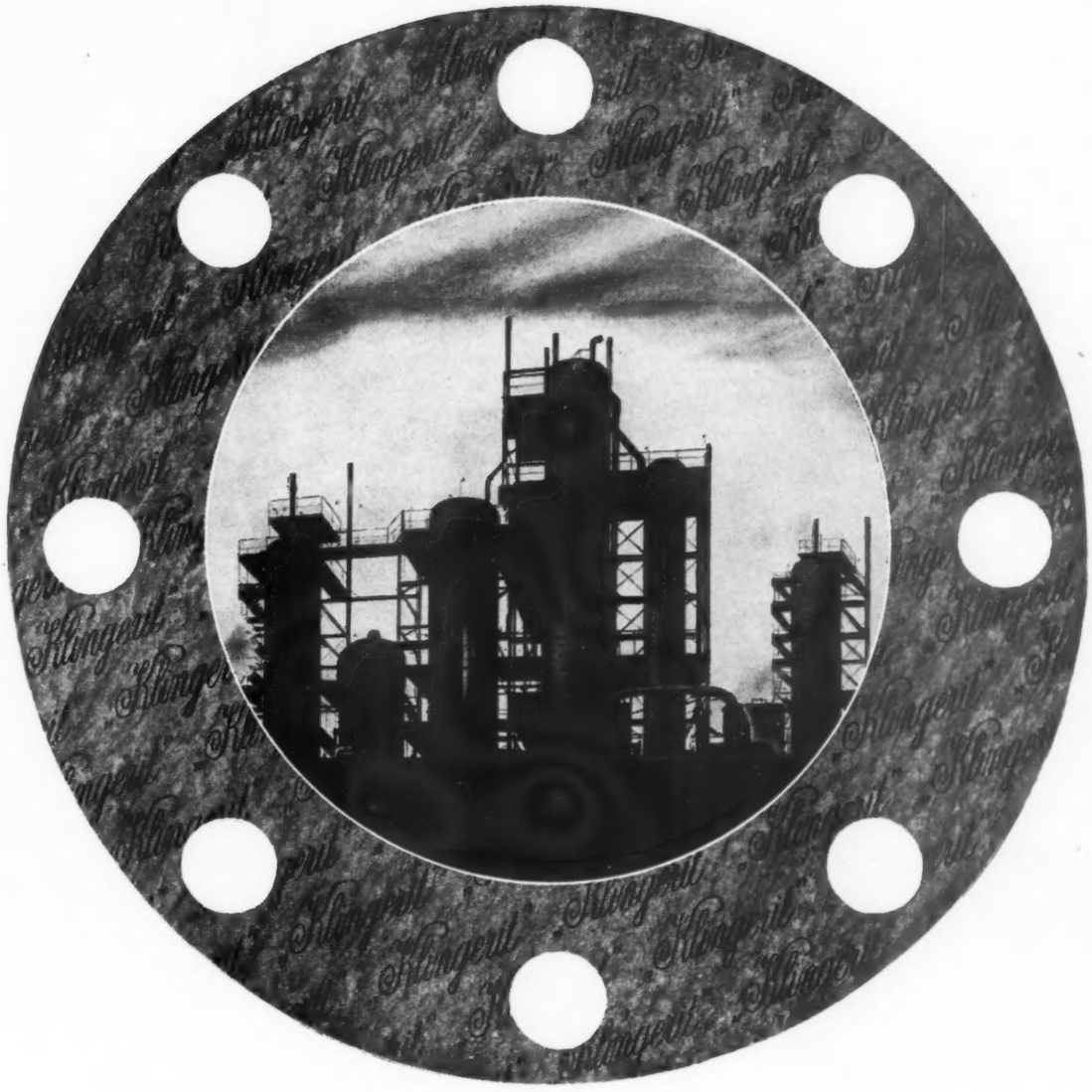

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(Continued from page 96)

interest to turn to the results obtained in our own country by use of vapor phase cracking, particularly by the Gyro, True Vapor Phase, and Cooke processes.

The Gyro Vapor Phase process for the production of high octane gasoline was installed by the Pure Oil Company, Carbide and Carbon Corporation, and others about 15 years ago. Considerable resistance was met by the sponsors of the process because it made an excessive amount of gas as compared with Cross, Dubbs and other liquid-phase units of the day. The production of this relatively large percentage of gases, for which there was no good and profitable market at the time, made it doubtful if Gyro would succeed. The Pure Oil Company, in particular, should be given the greatest credit for putting in capital and plants for this was pioneer work, which brought forth profits at a later date. The industry benefited from this work. Before the withdrawal of Gyro, the Gyro and Pure Oil Companies, along with Alco Products, had obtained very valuable basic data which is now so important to our war needs. This data showed the way, when the day came, to increase our output of aromatics, and still not have to build impossible numbers of coal coking ovens for the production of increased quantities of toluol, benzol, and other aromatics.

The work of Pure Oil, Gyro and Alco Products was carried on from 1927-1939. The Pure-Alco-Gyro group built plants in Europe to make benzol, toluol and other aromatics from butane, a then waste material in both Iran and in America. Aromatics were produced in quantity in the plants of the Pure Oil Company in America, and the production of butadiene was going on in Oklahoma. This advance work went by the wayside when Gyro plants stopped working for reasons more or less well known in the industry. The only Gyro plants which were kept in operation were the two at Shreveport, La., (belonging to independents) and those of the Carbide and Carbon Corporation, at Charlestown, W. Va. This company was established in the chemicals-from-petroleum business and continued to operate the plants of Gyro continuously to date. The plant in Iran was and probably is one of the best plants for the English to obtain aromatics for their Near East operations.

Great interest is now centered in the production of the side chain aromatics for the purpose of adding them to aviation blend stocks to give the aviation fuel the needed rich-mixture pull characteristics. The production of this material has been going on in polymerization plants for years but there was no interest in isolating it. The Ipatieff process (now Universal Oil Products process) of polymerizing gases by means of phosphoric acids has been known for a long time, and has been operated on a commercial scale since 1934 or 1935. The selective method has been used to produce dimer diisobutylene, or isooctene, as a raw material for hydrogenation to 100 octane aviation gasoline. This process involves the use of butylenes to produce the dimers and the trimers which will hydrogenate to aviation fuels. The same process, when operated on gases containing benzol, produces the union of the alkyl compounds, propylenes and ethylenes with the aromatic to give the side chain aromatics, ethyl benzenes and isopropyl-benzenes. The ethyl benzene is the best raw or intermediate material for the production of styrene, the second component of Buna S rubber. It is only necessary to dehydrogenate it for the production of styrene with a fine yield.

In the Gyro vapor phase system of cracking these materials were formed in the system and they were in the finished gasoline automatically, and this accounted for some of the superior characteristics of the vapor phase gasoline over the liquid phase product. The systems of TVP and of Cooke are also known to produce large quantities of the side chain aromatics. These systems form relatively large amounts of these materials because the hot carrier gas is controlled, as to composition, at the fractionating plant to give the necessary alkyl compounds, such as propylene and ethylene, so that the aromatic benzol is contacted as soon as it is formed in situ.

The Pure Oil-Gyro system of thermal polymerization was outlined at Los Angeles in 1935 at the meeting of the American Petroleum Institute, by M. B. Cooke. The system of Cooke was outlined at oil company meetings in the Mid-continent in 1936-37. The products made by these processes were discussed by M. B. Cooke at Paris, France, before the Second International Petroleum Congress, in 1937, in a paper "Organic Chemicals from Petroleum and Natural Gas."

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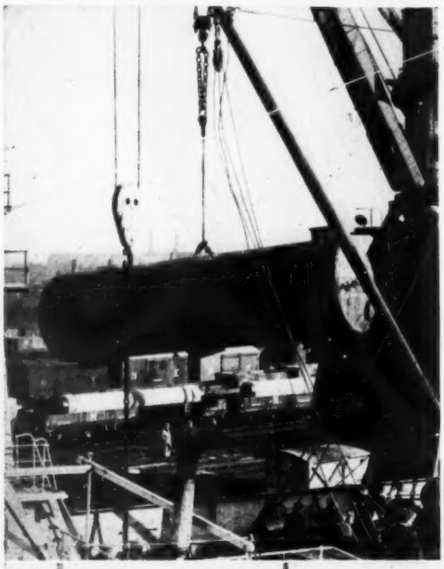

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WORLD PETROLEUM ABSTRACTS

Summaries of the Most Important Articles as Published in the Oil Press of the World Dealing with Technical and Economic Aspects of the Petroleum Industry — Edited by Dr. O. W. Willcox.

DRILLING

Trends in Rotary Drilling Machinery and Equipment—John M. Shimer, before 1st Annual Meeting AMERICAN ASSOC. OILWHEEL DRILLING CONTRACTORS, Dallas, November, 1941.

Aside from numerous small but cumulatively impressive improvements in pumps, especially mud pumps, engines, hoists, swivels, bearings, etc., probably the most outstanding improvement in rotary rigs in the past few years is the independent drive to the rotary table in which a separate prime mover is used instead of the hoisting engine.

There are several outstanding advantages in this type of rotary table drive which are (1) adaptability to higher table speeds; (2) reduced wear and tear on the hoisting engine; (3) possibility of drilling up through cavings; (4) more sensitive control of the speed and feed; (5) reduced noise on the derrick floor and (6) the rotary table driving engine is usually arranged to serve as a standby hoisting engine for emergency use.

Rotary table speeds of 500 R.P.M. and higher are uncommon in the Mid-continent area but are used quite generally in the deep wells in California. This type of service is very severe especially when taking into consideration that the horsepower requirements usually are calculated to be one horsepower per revolution per minute or 500 horsepower at 500 R.P.M. The modern rotary table represents probably the greatest advance in drilling machinery design. Having anti-friction bearings throughout, spiral bevel, accurately cut surface hardened gearing and complete oilbath lubrication, it performs the most difficult job on the rig with a minimum of maintenance cost. It is not inconceivable that before long, table speeds of 1000 R.P.M. may become quite common. It happens that at this time the maximum permissible speed is probably limited by the drill pipe and bits.

Driving the rotary table with a separate engine adds a small amount to the first cost of the rig but this is soon paid for out of savings in operating expense. Using a 2000 horsepower hoisting engine, operating at high speed to drive a rotary table which on the average requires less than 500 horsepower during all the time the bit is on bottom, obviously causes undue wear and tear of the large engine and of the chain drives, which likewise are operating at excessive speeds. No engine is efficient at quarter load and there is, therefore, a considerable power loss and excess fuel consumption.

It is especially emphasized that a separate engine for turning the rotary table makes possible the taking of an upward strain on the drill pipe with the hoisting engine while rotating, and thereby drilling up through cavings which may have fallen in above the bit and which might otherwise cause a stuck drill pipe and a fishing job. Likewise the breaking out of the drill pipe while coming out of the hole is facilitated since there is no rotary clutch to operate.

PIPE LINES

Crude Oil and Gasoline Pipe Lines in the United States on May 1, 1941—G. R. Hopkins and F. S. Lott in BUREAU OF MINES INFORMATION CIRCULAR No. 7196 (December, 1941).

As of the date of this publication the crude petroleum pipe lines of this country had a total length of 118,350 miles. The total length of gasoline pipe lines was 9,001 miles, excluding several hundred miles under construction. The average diameter of all crude-oil pipe lines is 8.4 inches;

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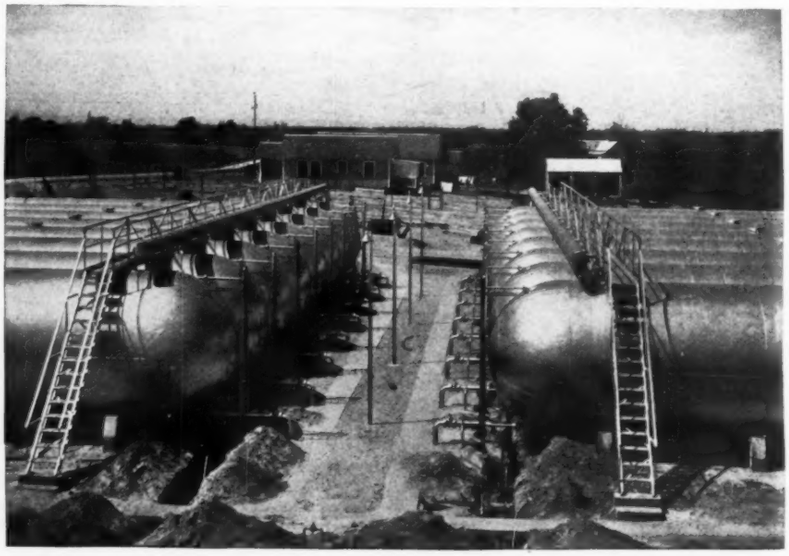

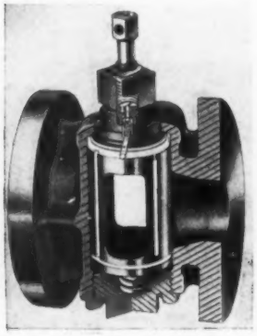

★ This sectioned illustration of a flanged Newman - Milliken Valve shows the cylindrical plug and lubricant ducts which seal the valve against leakage and ensure easy operation at all times. A rectangular port valve is shown, but full round port valves are also manufactured.

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74 percent of all these lines is 8 inches or larger. The mileage of crude-oil lines of 4 inches diameter or smaller is decreasing. Gathering lines total 53,170 miles. Gasoline lines vary in diameter from 2 to 12 inches; the weighted average is 7 inches. The trunk line fill, or amount of crude oil in transit through the pipe system is figured at 23,448,000 bbl. Trunk line facilities increased in most states since 1936; the mileage in Oklahoma has decreased rather sharply since 1931, and small reductions are noted in Arkansas, North Louisiana, New Jersey and Pennsylvania. Gathering lines of necessity increased in areas under active development and declined in areas of settled productions.

The authors summarize technical developments in pipe line operations in recent years. Aerial surveys for location of long lines are standard practice. Time and cost of construction have been decreased by using welding instead of couplings for joining pipe lengths, 40 foot for "double" lengths, factory made bends, and power machines to apply protective coatings. By using forged steel fittings, cast alloy steel valves, and stronger materials, operating pressures as high as 2000 lbs. have been achieved with safety, and on some new lines the high-pressure construction has permitted pumping stations to be spaced 100 or 200 miles apart instead of 40 or 60.

The efficiency of field gathering-line systems has been raised by the modern practice of installing small, automatic pump stations, which eliminate the need for pump houses and are easily moved as conditions change.

Although still in the pioneering stage of development, synchronized operation of all stations along a trunk line has proved advantages that promise its wide use on long lines. The system permits better pressure control and prompt detection of line losses, and eliminates the need of "floating" tanks at pump stations.

Dependable oil meters have been developed in recent years, suitable for some pipe-line purposes. They are finding an increasing field of usefulness, particularly in California, both for measuring quantities of oil and for checking oil losses from pipe-line systems.

An important step toward reduced maintenance costs of prime movers at pump stations has been the adoption of closed systems for cooling water. By their use much expense and shut-down time are avoided through control of scale formation and of corrosion in cylinder jackets. Wear of moving parts has been greatly retarded by removing foreign matter from lubricating oils and fuels.

The Amount and the Measurement of Internal Corrosion in Gasoline Pipelines—J. M. Pearson, before AMERICAN PETROLEUM INSTITUTE, 22nd Annual Meeting, San Francisco, November, 1941.

Difficulties in obtaining an accurate idea of the amount of internal corrosion in a gasoline line are discussed in connection with the available data.

The results of measurements of débris removed, of measurements of the pipe wall, and of corrosion suffered by test coupons are compared. The rates of corrosion determined so far vary from less than 0.1 up to 2 per cent of the pipe weight per year, depending upon location relative to gasoline storage used as the source, and upon other factors such as throughput, use of scrapers, etc.

A method of measuring the weight loss of a test joint of pipe in a continuously operating line is described. The relation between weight per unit length, temperature, and electrical conductivity is used to determine the pipe weight at any desired time by means of electrical measurements. Application of the method will serve to determine distributions of corrosion; it will serve also as a control to determine the effectiveness of any remedial measures taken, or to determine the effect of scraping on corrosion rates.

After observing that the present data are not complete enough for really quantitative conclusions, the following general statements are made:

1. The rate of corrosion is higher in proportion to the amount of moisture and oxygen introduced into the pipe line.

2. The rate of corrosion is highest at the point where these elements enter the line, and drops rather sharply at the more remote points.

3. Depending upon pumping rates (1), and upon location (2), the weight-loss rates of corrosion vary from 0.1 to 2.0 per cent of the pipe wall per year.

4. There is some evidence that scrapers used to improve gasoline-line capacities increase the average rate of corrosion.

5. The data contain no reason for alarm in regard to the effect of internal corrosion on the life expectancy of gasoline lines. Soil corrosion and other external factors still deserve first consideration.

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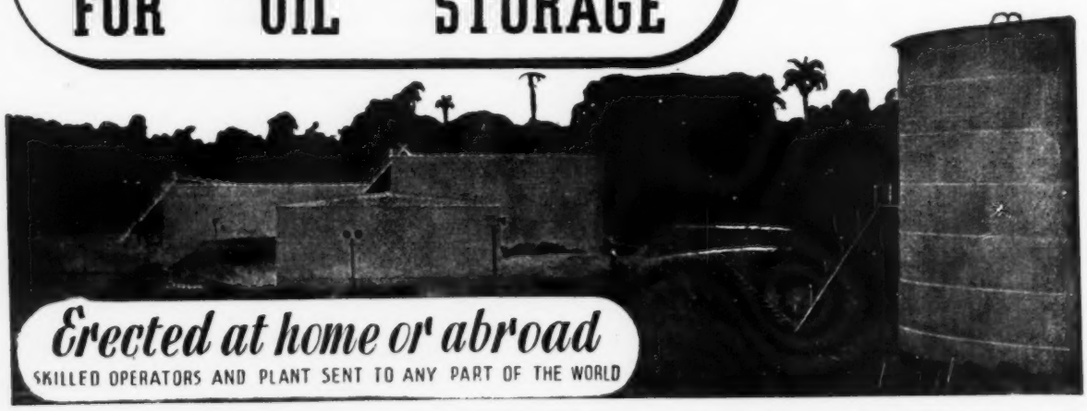

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